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JUL 80 D B SIMONS, Y H CHEN DACW25-80-C-0017

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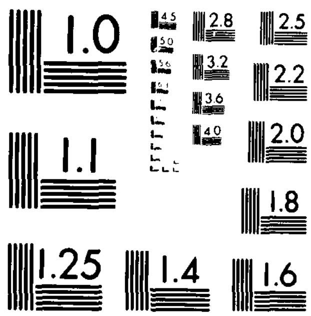

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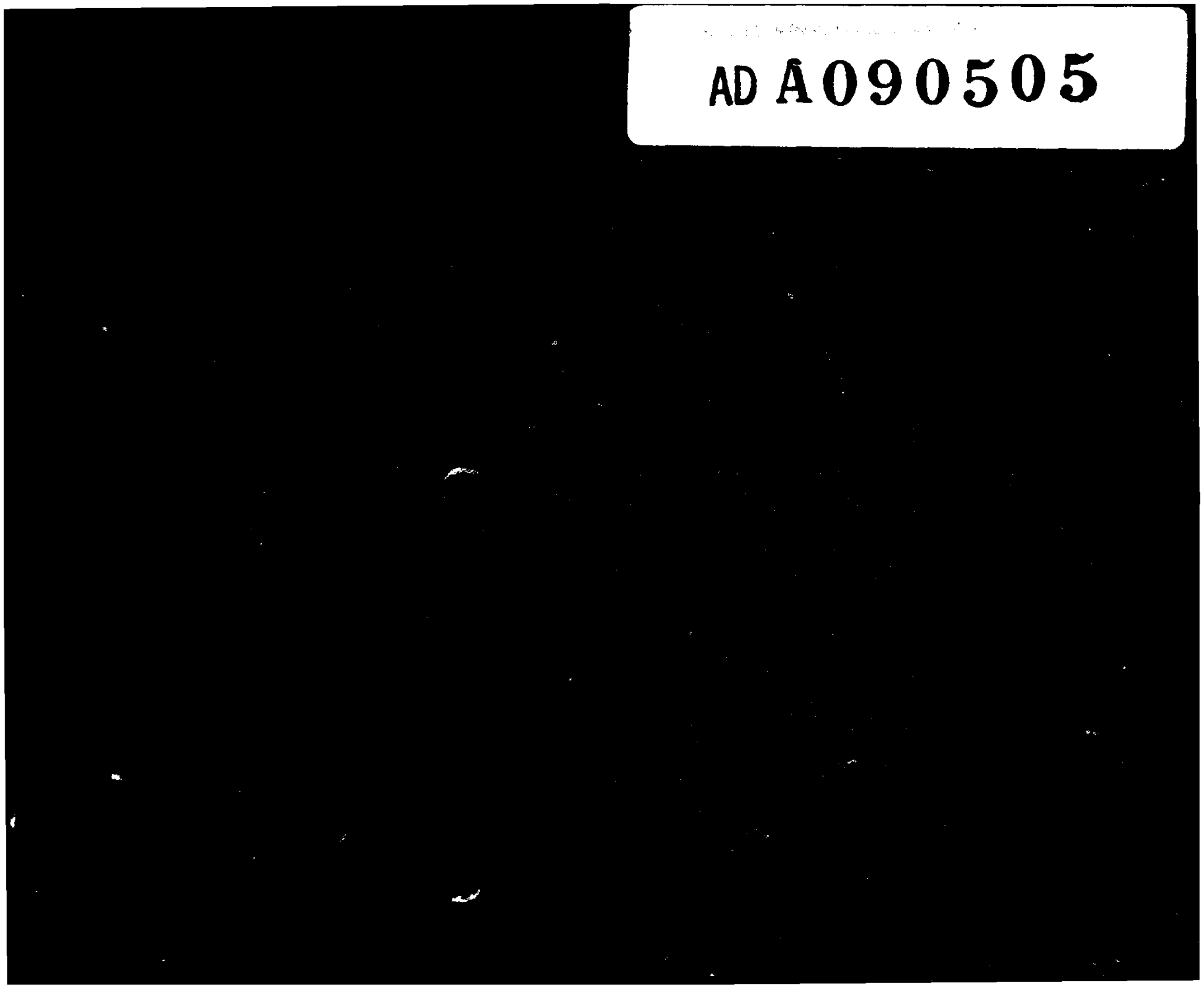
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PLANNING OF A DEMONSTRATION PROJECT FOR MAIN CHANNEL DISPOSAL OF DREDGED MATERIAL.

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Prepared for

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ROCK ISLAND DISTRICT

Rock Island, Illinois

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FOREWORD

This study was performed under Contract No. DACW25-80-C-0017 titled "Demonstration Project Report for Main Channel Disposal of Dredged Material," between the U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois and Colorado State University. This report describes a plan for establishing a demonstration project for main channel disposal of dredged material in the Upper Mississippi River. Different tracer methods for tracking the movement of dredged material disposed on the thalweg were reviewed. A suitable tracer method for this purpose was identified. Then a plan for establishing a demonstration project for main channel disposal of dredged material was developed. This plan consists of selecting disposal sites, determining amount, source, labeling and life expectancy of tracer material, identifying detection equipment, establishing field dosing procedure, and developing a data collection program which identifies data needs, equipment needs and methods for collection and analyses of samples, sampling frequencies and spacing and cost estimate.

The study was supervised by Mr. J. Crittenden, Chairman of GREAT II Dredging Requirements Work Group. Other personnel contacted in the Rock Island District include Mr. R. J. Fleischman, Mr. J. P. Hoorebeck and Mr. R. H. Reesink. Drs. D. B. Simons and Y. H. Chen, Civil Engineering Department, Colorado State University, were the principal investigators. They were assisted by Mr. A. J. Tsivoglou and Ms. C. T. Chen. Mrs. M. I. Reuss typed the draft report. The study period was from October 1979 to May 1980.

PLANNING OF A DEMONSTRATION PROJECT FOR MAIN

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Chapter 1

INTRODUCTION

1.1 INTRODUCTION

The U.S. Army Corps of Engineers, Rock Island District maintains a 314-mile long navigation channel in the Upper Mississippi River between Guttenberg, Iowa (Lock and Dam 10) and Saverton, Missouri (Lock and Dam 22). To accomplish the maintenance of this reach of navigation channel, the Corps must dredge large volumes of material each year. The dredged material is generally disposed of in the river environment, that is, along bank lines, in side channels, on marshes and on islands. The primary impacts of this disposal are possible reintroduction of the material into the river and possible sterilization of biologically productive habitats. GREAT II (Great River Environmental Action Team) was founded because of increasing concern by conservationists and the general public over natural resource destruction resulting from the Corps of Engineer's channel maintenance activities, dredging and disposal, channel control structures, and other activities.

A comparison of the environmental impacts of dredged material disposal with the geomorphic and hydraulic consequences of open water disposal has revealed areas of serious conflict. Quite often, locations that constitute the most desirable disposal sites based on an analysis of the physical processes of the river system are judged to be undesirable when the biological processes are considered. Physically, the best locations for disposal are in regions where deposition would occur naturally. These include the downstream portion of point bars and other locations not directly subject to high velocities during either high stage or low stage flow. The man-induced depositional environment of the dike fields offers protected

disposal sites, as does the interior of many alluvial islands. However, disposal in these locations usually involves serious and often unacceptable environmental impacts. The only remaining significant portion of the riverine environment that offers potential disposal locations is the main channel or thalweg region of the river itself.

The concept of main channel disposal (thalweg disposal) is supported by a general geomorphic point of view. In a meandering stream, the longitudinal profile of a river appears as an irregular series of high points and low points. The high points of the profile generally correlate with the crossings and the low points with the deep bendway pools. At high stage, sediment tends to flush from the pools and adjacent point bar areas and accumulate on the crossings, reducing the depth of flow. At low stage, the process is reversed. However, low stage scour on the crossings is often not sufficient to produce required navigation depths during the low-water season. This sequence of deposition and scour results in repetitive dredging requirements on the crossing. In regard to maintenance of a navigation channel the crossings can be visualized as sediment source areas and the pools as sediment sink areas during periods of low flow. The concept of thalweg disposal then, involves dredging a crossing source area and disposing the dredged material in a downstream pool or sink area.

This thalweg disposal method was utilized by Hopman (1972) for maintaining a navigation channel in the Columbia River. Also, U. S. Army Corps of Engineers, Portland District (1973) applied the same approach to improve maintenance of small isolated shoals, and St. Paul District applied this method to the Lower Pool 4 area in the Upper Mississippi River with some degree of success. In 1975, Simons, et al.,

(1975) developed a mathematical model of a particularly troublesome reach of Pool 25 in the Upper Mississippi River to evaluate the feasibility of thalweg disposal. The field experience, geomorphic study and mathematical analysis all indicate that dredging from a crossing and disposing the dredged material in a downstream pool can provide a feasible solution to the disposal problem in certain cases. The process involves a degree of risk of affecting the integrity of the channel downstream of the disposal site. However, the risks incurred would be outweighed by the potential environmental benefits at many locations. Further investigation is required to evaluate the feasibility of main channel disposal in various river environments.

The overall objective of this study is to develop a plan for the demonstration program for main channel disposal of dredged material. The final goal of this task is to ascertain if main channel disposal is an acceptable practice and to determine what trade-offs are involved.

1.2 ORGANIZATION OF REPORT

In Chapter 2, a literature search of alternative methods for tracking the movement of sand in a riverine environment is presented. Tracer methods that are suitable for tracking the movement of dredged material disposed of in the thalweg in a large river are selected in Chapter 3. Development of a plan for conducting the demonstration project is presented in Chapter 4. Chapter 5 summarizes the study results.

Chapter 2

REVIEW OF METHODS FOR TRACKING MOVEMENT OF BED MATERIAL

2.1 INTRODUCTION

Two general categories of methods are available for determining the movement of bed material. The first category of methods utilizes tracer methods which directly track movement of sediment by tracers. The second group of methods requires surveying the bed elevation changes with time. Sonic sounding methods are most commonly used for surveying riverbed contours. Based on superimposing riverbed contour changes, the movement of sand wave can be determined. This in turn, provides general information regarding the sediment movement. This method, also known as hydrographic survey method is relatively easy to perform, but its accuracy is limited due to the measuring limits of equipment (about $\pm$ 0.5 ft). Also, at high flow the natural sand wave may overtake the dispersing wave of disposed dredged material and make the tracing of disposed material difficult.

The tracer methods do not encounter problems as severe as those mentioned above. With proper selection of tracers and design and execution of data collection program, fairly accurate results can be obtained. In this chapter, tracer methods are reviewed and their applicabilities are discussed.

2.2 SEDIMENT TRACER PARTICLES

During the past two decades three labeling methods, fluorescent tracers, radioisotopic (radioactive) tracers, and stable isotope tracers, have become available and have proven useful in tracing sediment movement. To gain true scientific results from a sediment tracing experiment in a fluid environment, it is imperative that the labeled sediment

particles have the same hydraulic behavior after labeling as before. Also, the labeled particles should resist leaching, abrasion and decay of traceable property. However, all the labeling techniques more or less alter the hydraulic behavior of the natural sediment and should be carefully examined by mainly checking alterations of sediment sizes and fall velocities before utilization. The cost of conducting these tests will be included in the design of the demonstration project as will be discussed in Chapter 4.

2.2.1 Fluorescent Tracers

The ideal fluorescent tracer should be fluorescent, and have the correct size, shape and density. It must resist abrasion, and should there be some abrasion, it should nevertheless retain adequate fluorescent properties. The concrete tracer pebbles and the sand tracers were used by Vendrov, et al. (1957),Zenkovitch (1958), Russell (1960), Gole and Amie (1963), Russel, et al. (1963), Brown (1969), Grigg (1969), and others, in the field and in the laboratory.

The concrete tracer pebbles consist mostly of a dense concrete containing particles of fluorescent plastic. Particle size can be controlled by sieving. Density and abrasive resistance can be controlled by adequately mixing cement and pebbles. However, little attention has been paid to particle shape. Usually, the pebbles produced by crushing and sieving appear to be neither sharper, flatter, or rounder than normal beach pebbles. Therefore, they are not further treated to alter their shape. The dye Rhodamine "B" or "WT" (red), Primuline (blue), Eosine (orange) and Auramine (yellow) have been used in mixing the fluorescent plastic. Other dyes and phosphors have also been used or tested. Thirteen parts cement, 26 parts quartz dolorite and 1 part granulated dyed plastic have proven to be suitable proportions. Other mixtures may work equally well.

Sand tracers can be produced by taking sand from the areas to be studied and coating each grain with a thin layer of fluorescent plastic. The process involves mixing sand with a liquid fluorescent resin, allowing it to set into a cake, disintegrating the cake so that the individual particles are again separated, and then sieving to exclude particles of the wrong size. Another process utilizes acetone solution to dissolve fluorescent dye and vinyl plastic to form the tagging solution. This solution is then mixed with sediment in a concrete mixer. Because of the fast evaporation of the acetone solution during mixing, tagged particles come out dry and separate. This avoids disintegration and sieving procedures. A potential problem is the alteration of the surface of the sand grains after they have been treated. This alteration may significantly affect the hydraulic properties of the tracer sand thereby making interpretation of results difficult. To alleviate this problem, Ingle (1966) applied a liquid detergent to the fluorescent grains prior to their release at the test site. It is recommended that the hydraulic properties of the tagged sediment be determined and compared with those of natural sediment before the utilization. This can be done by checking the particle size and fall velocity utilizing a fall velocity column or a visual accumulation tube.

Nearly all the fluorescent pigments and hydro-carbons are subject to photolysis, i.e., their brilliance decays under the action of ultraviolet light. Fluorescein tends to decay in a few days, but might be useful for tests where the durability is not important, or where a short lift is an advantage. Kiton Yellow, Rhodamine "B" extra 525%, Uvitex SWN were all found to retain maximum brilliance when exposed to unfiltered UV tests equivalent to one-year natural weathering.

2.2.2 Radioactive Tracers

Radioactive tracers are generally manufactured by treating the sediment particles using radioactive isotopes. The accuracy of the radioactive tracer technique increases as the level of radioactivity increases. However, as the level of radioactivity increases so does the possibility for harmful contamination to the environment. Hence, instrumentation must be designed to provide satisfactory accuracy in the measurements and at the same time limit radioactivity to a safe level.

Because the tracer particles move primarily as bed load, "in situ" measurements seem to be the most feasible means of defining the transport and disperison of particles. Such measurements virtually necessitate the use of a gamma-emitting radionuclide because the penetration range of alpha and beta radiation is limited to only a few centimeters in water. Therefore a good radioactive tracer should emit gamma rays having sufficient energies that detection under water is possible, and have a suitable half-life. Hence, radioactivity should decay slowly enough to be readily detectable during the entire experiment, but rapidly enough to preclude long-term contamination of the waterway. Also, the tracer should be obtainable and economical.

Tracer particles can be manufactured by grinding glass or silica particles to an appropriate size distribution; then labeling them with an incorporated radioactive isotope. The manufacturing methods generally preferred is to incorporate an inactive isotope as the label in the glass and activate it by irradiation in a nuclear reactor just prior to use. It is possible to handle relatively large amount of manufactured tracer but the tracer may not behave hydraulically in the same manner as natural sediment particles.

Natural sediment materials have been labeled with dissolved radioisotope by investigators interested in closer simulation of the natural sediment. The solution of radioisotope is usually prepared by a major tracer supplier such as Oak Ridge National Laboratory or Argonne National Laboratory according to standardized procedures, outlined in the publication by International Atomic Energy Agency Technical Report, Serial No. 128. The solution is then taken to the field study site where upon mixing with sediment in some form of shielded container

it becomes adsorbed onto the sediment particles. Sorbed labels also have the advantage of facilitating the preparation of large amounts of tracer particles. The disadvantage of sorbed labels for sand tracing are the nonuniformity of sorption on different minerals. Also, the labeling amount is proportional to surface area rather than mass. A solution to these disadvantages is to diffuse radioactive gas into sediment at high temperature and pressure such that sediment particles are tagged almost uniformly due to high stress conditions.

Natural sediment materials can also be irradiated in a reactor when subjected to neutron bombardment. The period of irradiation is estimated based upon specific activity desired. Adequate sheilding of field personnel is easily attainable with proper precautions. Problems associated with this method include inability to achieve uniform activity throughout tagged materials due to different target materials and impurities present. Also, it is not easy to handle large amount of sediment by the reactor facility.

A number of radioactive labels being used are summarized in Table 2.1. Methods for tagging tracers, and their half life, emitting energy, gamma-ray percent intensity and maximum permissible concentration of

TABLE 2.1 Radioactive Tracers

Tracer	Investigator	Treatment	Half-life days	Energy (million electron volts)	Gamma-ray percent intensity	MPC_w (pci/ℓ)*
Silver-110 solid sludge	White (1976)	Absorption	270	2.9	--	20,000
Copper-64 tagging natural sediment	Campbell, et al (1967)	Absorption	0.53	7.08	--	200,000
Gold-198 tagging natural sediment	Krone (1960) Cummins (1964) Hart (1969) Tool (1976)	Absorption	2.7	0.41	95	50,000
Iron-59 tagging solid sludge	Scalf, et al (1968)	Absorption	45.1	1.10	56	50,000
Scadium-46 tagging natural sediment	Sauazay, et al (1977)	Absorption	84	1.12	100	40,000
Cesium-137	Ritchie, et al (1970) McHenry and Ritchie (1977)	Fallout associated with testing of nuclear bombs	11,000	varied	--	20,000
Iridium-192 tagging natural sediment	Sayre & Hubbell (1963)	High temperature oxidizing	74	0.90	70	40,000
Barium-140 tagging natural sediment	U.S. Naval Radiological Defense Lab (USNRDL)	High temperature and pressure diffusion	12.8	0.54	29	30,000

TABLE 2.1 (continued)

Tracer	Investigator	Treatment	Half-life days	Energy (million electron volts)	Gamma-ray percent intensity	MPC_w (pci/ℓ)*
Chromium-51	USNRDL	High Temperature and pressure diffuser	27.8	0.32	9	2,000,000
Lanthanum-140 tagging natural sediment	USNRDL	High temperature and pressure diffusion	1.7	1.6	97	20,000
Xenon-133	Duane & Judge (1969)	High temperature and pressure diffusion	5.27	0.08	35	--
Glass sand	Sato, et al(1961) Kato, et al(1963)	Irradiation	--	--	--	--
Quartz sand	Inman & Chamberlain (1959)	Irradiation (phosphorus-32, slow neutron)	0.61	1.71	--	--
Natural Sand	Crickmore & Lean (1962)	Irradiation (sodium-24, bromine-82)	1.5 0.63 1.5	 5.51 3.09	-- --	-- --
Cesium-137 (Radioacitve Microsphere)	Hung (1975)	Manugactured	11,000	0.66	85	20,000
Scadium-46 (Radioactive Microsphere)	Svasek & Engel (1962) Grigg (1969)	Manufactured	84	1.12	100	40,000

*Maximum permissible concentration due to continuous lifetime exposure in 10^{-12} cury per liter of water recommended by the National Committee on Radiation Protection (U.S. Department of Commerce, 1959)

exposure are given in the table. In general, the higher the activity of the isotope, the lower the amount of tracer required for successful measurement. The shorter the half-life of the material the higer the initial activity can be. The less the forms of daughter products and energy releases the higher the likelihood of non-interference in measurement. The lower the energy level the safer the material will be in handling but in general, it will also have a longer life.

It is considered better to select a low-level single particle emitter having a short to medium duration half-life and a high activity.

It can be seen that most of the radio-active tracers are treated or manufactured particles. The following organizations are useful sources of infromation in the preparation of a radioactive tracer experiment:

1. Oak Ridge National Laboratory
   Isotopes Production Division
   Oak Ridge, Tennessee

2. Argonne National Laboratory
   Chemical Division
   Argonne, Illinois

Both sources could give little specific information regarding costs and procedures because each tracer experiment presents different problems that cannot be handled in a generalized fashion. Oak Ridge National Laboratory (ORNL) is not regarded as a supplier of commonly used radioisotopes as these isotopes are available from many commercial firms. ORNL is operated for the Department of Energy by the Union Carbide Corporation and will supply only certain isotopes that are not commercially available. ORNL is also able to handle limited amounts of samples for irradiation purposes but does so only under special contract. For common or large scale irradiation, several major universities

(i.e., University of Missouri at Columbia, Nuclear Engineering Department) are equipped with research reactors and are able to do contract work for off-campus organizations. However, to irradiate a large volume of sediment would be prohibitively expensive.

Oak Ridge National Laboratory also gave reference to the following commercial firms as non-governmental sources of radioisotopes:

1. New England Nuclear, Inc.
   Boston, Massachusetts
2. Movsants Research, Inc.
   Dayton, Ohio
3. Union Carbide, Corporation
   New York, N. Y.

All provide catalogs concerning the isotopes that are commercially available at no charge. It seems that the commercial supplies are used primarily by the medical profession in procurement of tracers of small dosages. Large scale experiments such as a river radioisotope tracer experiment require special consultations and inquiries.

2.2.3 Stable Isotope Tracers

In the neutron activation technique of using stable isotope tracers, a small amount of a chemical not naturally present in the sediment (or present in very low concentrations, e.g., less than one-fifth of that being added) is attached to sediment and subsequently introduced into the environment of interest. After some period of time, sediment samples are collected, processed, neutron activated, and the gamma-ray spectra determined. From this data, the presence of the tracer can be quantitatively determined and the movement of sediment can be determined.

In selecting stable isotopes to be used as a tracer, the chemical elements must not be naturally present in any significant concentration in the medium being traced or in the media with which the trace material is mixed. Procedures must permit homogeneous labeling of the sediment.

Isotopes must remain fixed to the specified particles and not alter their hydraulic characteristics. The treated particles must not be toxic to the life forms in the environment. Also, they must have isotopes which can be measured in the part per billion range through neutron activation analysis.

Rare-earth isotopes studied by various researchers are given in Table 2-2. Malone (1969) selected europium, and Boone and Slowey (1972) selected dysprosium to study transport of coastal sand because they could be analyzed immediately after activation to avoid decay of the rare-earth tracer activity. However, Leahy et al. (1976) selected irridium to trace the dredged sediment movement, because it is less expensive, its longer half-life will permit delaying the time of sample counting until the short half-life nuclides have decayed, and it is sensitive and easier to apply and analyze.

TABLE 2.2. Rare Earth Elements

Isotope				
Stable	Radioactive	Irradiation Time	Half-life	Energy (million electron volts)
La-139	La-140	-	40.2 hr	3.77
Eu-151	Eu-152	10 min.	9.3 hr	1.82
Sm-152	Sm-153	4 hr	47 hr	0.80
GD-158	Gd-159	4 hr	18 hr	0.95
Tb-159	Tb-160	4 hr	73 days	1.72
Dy-164	Dy-165	1 min	2.3 hr	1.30
Ho-165	Ho-166	4 hr	26.9 hr	1.85
Yb-174	Yb-175	-	4.2 days	0.47
Lu-176	Lu-177	4 hr	6.8 days	0.50
Ir-191	Ir-192	4 hr	74 days	1.45

2.3 DETECTION EQUIPMENT

Labeled sediment tracers can be studied by making on-site measurements or by collecting samples from the environment that are analyzed later in a laboratory (off-site analysis). The latter technique is usually used for studying flourescent tracers and stable isotope tracers. The flourescent tracers can become brilliantly visible under an ultra-violet light and can be counted. This technique is usually laborious and time consuming when a large number of samples are analyzed. An automatic counting system is available from Cambridge Instrument Co., San Francisco, Calif., which can determine the concentration of tracers and measure particle sizes of a number of samples in a short period of time. Another technique of tracking flourescent tracers is by using an underwater TV camera monitoring system equipped with ultra-violet light to photograph the riverbed surface for later counting in the laboratory plus some bed core sampling for calibrating the relation between the number of tracers found on the riverbed surface and the tracer concentration. This technique is more accurate as larger areas can be sampled. Also, the movement of tracer particles can be visually tracked. However, this underwater TV camera monitoring technique is still in an experimental state. It is not clear at this point in time whether or not turbidity will significantly affect the accuracy and efficiency of this detection system. Nevertheless, ultra-violet light of higher intensity can be utilized in a more turbid water environment to reduce the effects of turbidity.

The samples of stable-isotope tracers, after being collected from the field, can be analyzed using two methods: direct sample examination method and separation-detection method. The direct sample examination method involves directly neutron-activiating the sediment samples and

measuring the gamma-ray spectra of the irradiated samples. By comparing the gamma-ray spectra of labeled sediment with that of natural sediment, the dispersion of sediment material can be determined. This direct sample examination method may have significant background interference problems which produce noise and affect the accuracy of the measurement.

If a suitable signal-to-noise ratio for analysis of stable-isotope tracers cannot be obtained, a separation-detection method is utilized. This method involves separation of the rare-earth labels (tracer-elements) from the sediment so that an instrumental analysis can be performed without the interference of other elements. Leahy, et al., (1976) investigated three methods: 1) chemical separation using dissolution and precipitation methods, 2) radio-chemical separation using dissolution and carrier separation, and 3) fire assay procedures. He found tnat the chemical separation method is not suitable for sediments with low concentrations of labeled sediments. The radio-chemical separation method is costly because of the amount of material that must be irradiated, the safety measures required for handling the radioactivity, the need for time scheduling of operations and the difficulty of dissolving the sediments. He found that the fire assay procedures were feasible and less costly for analysis of San Francisco Bay sediment. Fire assay is a process routinely used in the assay of ores for noble metals. In the procedure, finely divided ore is mixed with lead oxide, a reducing agent such as starch and fluxing materials, sodium carbonate and borax. This mixture is heated until it melts. Upon melting, the mixture separates into two liquid phases with the ore staying on the top in a slag phase and with noble metals plus a few other elements contained in the heavy metallic lead phase on the bottom. The fire assay process

can be performed on the sediment samples prior to neutron activation. This permits the use of a large sediment mass while eliminating many elements which produce undesirable noise in a sample being counted.

When the off-site analysis technique is applied to study radioactive tracers, problems of radiation exposure may occur. On-site measurements minimize radiation exposure problems and provide data rapidly. On-site measurements can be made by holding a radiation detector against the sediment and obtaining discrete readings. This system usually includes a detector, a pulse-height analyzer, a count-rate meter and a recorder carried by a vessel. A general description of this system is shown in Fig. 2-1. Quite often bundles of Geiger Muller detectors were mounted on a sled or drag, and towed on the surface of the channel bed or oceanic floor. These detectors are large, rugged and low in cost, but they have measurement efficiencies of only about 1 percent. Other investigators (for example, Sayre and Hubbell, 1963; Hung, 1975; Tool, 1976) used NaI (Sodium-Iodide) phosphor scintillation detectors which have smaller active volumes but can be very efficient (see Fig. 2-2). The sled mounted detectors have been used in rivers, protected harbors and some estuaries with satisfactory results. However, the sled may tip over, disrupting the survey. Such a system would likely be unstable in the surf zone and would be unsuitable in rocky areas. A ball-like device that would roll along the bottom was used by Duane and Judge (1969) in surf and topographically rough areas (see Fig. 2-3).

In order to establish a relationship between the counting rate and the concentration of tracer particles, the detection equipment should be calibrated with tracer particles. This is usually done in the laboratory by measuring counting rates of the detector for a natural sediment and tracer mixture with known concentrations. In the calibration, known

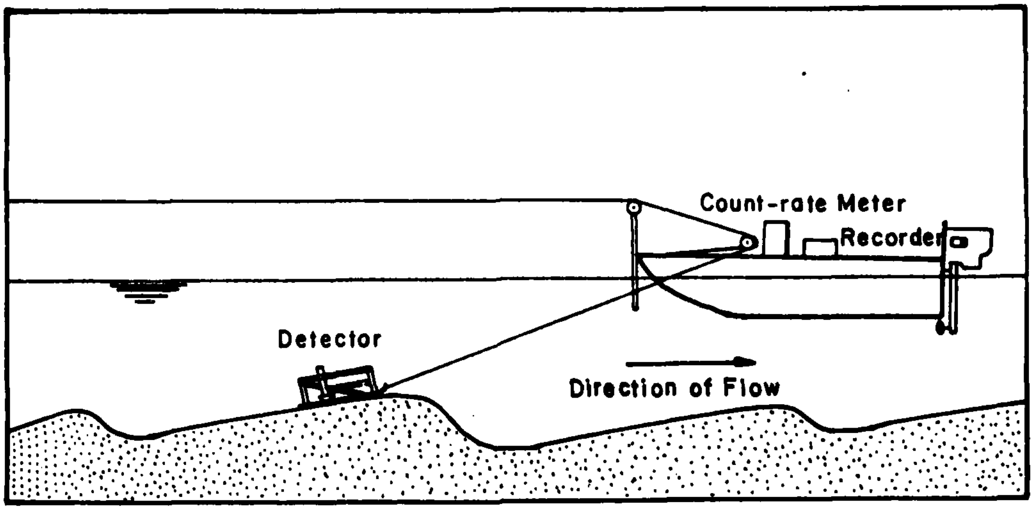


Fig. 2-1. Arrangement of Radiation Detection Equipment

amount of labeled sand are mixed thoroughly in a container with the natural bed material. For each concentration, an average counting rate is determined by placing the detector at different locations on the surface of the sediment; each counting location is selected so that the detected geometry is similar to that in the natural stream. To simulate more realistic conditions, a depth of water is maintained over the bed throughout the calibration procedure. The thickness of bed through which the particles disperse may vary and affect the counting rates accordingly. Calibration relation should include the depth of tracer particles as a parameter. More detailed description of calibration methods and instrumentation are given by Crickmore and Lean (1962), Sayre and Hubbell (1963), Galvin (1965), Hubbell and Sayre (1965), and others.

Some portable radiosotope gauges for measuring suspended sediment are available. For example, the sediment gauge described by Papadopoulos

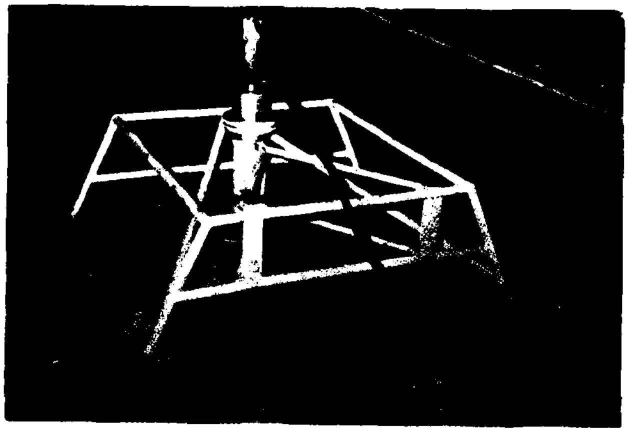


Fig. 2-2. Sled and Scintillation Detector
(after Sayre and Hubbell, 1965)

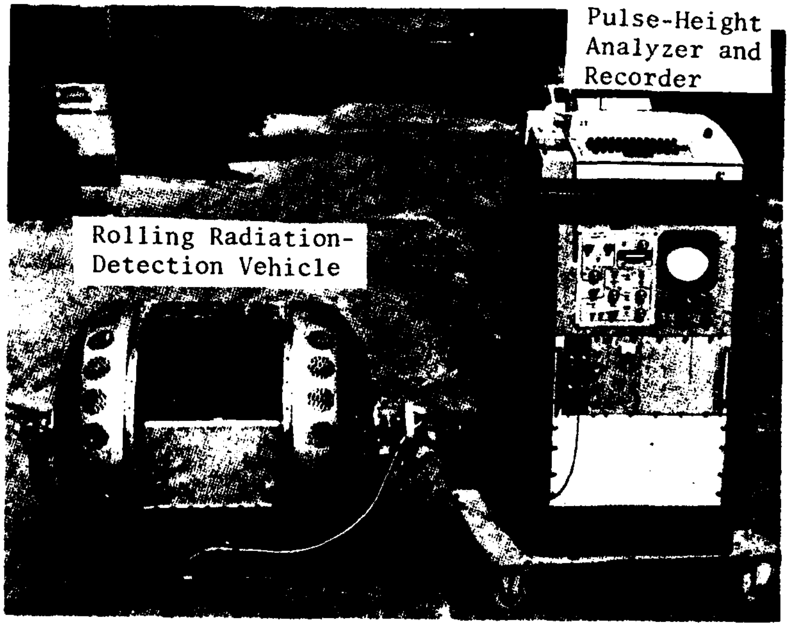


Fig. 2-3. Radiation Detection System
(after Duane and Judge, 1969)

and Ziegler (1965) operates on the transmission principle with a Cd-109 X-ray source. It can be installed on the river bank to continuously record the suspended sediment concentration. Florkowski (1970) described a gauge with an Am-241 radioisotope source, using attenuation of scattered photons as a measure of sediment concentration (see Fig. 2-4). These portable instruments proved to be quite easy to operate in the field and useful in small streams or for cross-sectional measurements.

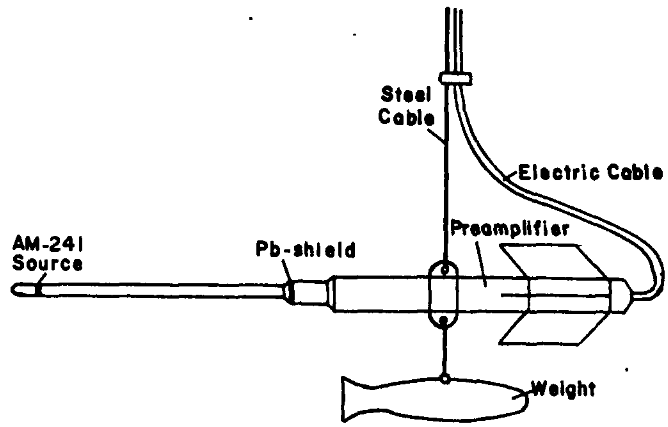


Fig. 2-4. Portable Am-241 Scattering Probe (after Florkowski, 1970)

2.4 FIELD PROCEDURE

The field operation of the tracer method includes the placement of tracer particles and the collection of data. Placement of tracer particles can be continuous or intermittent, on a spot or along a selected path, and in the water or on the surface of bed. In general, the dilution method injects the tracer into the channel at a certain spot at a known steady rate for a long time. The tracer method places large amounts of tracers on the surface of bed using a sink tank at selected time periods and locations.

The injector usually consists of a movable funnel tube and a rate adjustable device to inject the tracer at a selected elevation at a known rate (e.g., see Fig. 2-5 used by Sayre and Hubbell, 1963). The sink tank consists of a tank with a door and a control device to sink the tank to the bed and release the tracer from the tank (e.g., see Fig. 2-6 used by Duane and Judge, 1969; Tool, 1976). In this study, tracer particles can be directly injected to the transporting pipeline at a suitable rate to mix with the dredged material before its disposal. The exact location where the tracer is placed must be determined before or during the dosing.

Field data collection includes: tracing the labeled particles, sampling bed-material, and measuring hydraulic conditions. Tracing of the radioactive particles can be accomplished by towing the detector on the surface of bed and recording the counting rate using a count-rate meter and a recorder for later analysis. The bed material can be collected by using the core samplers (ASCE Task Committee, 1975). The bed material samples can be analyzed later in the laboratory to determine the characteristics of bed material and concentration of tracers. The hydraulic conditions can be measured by conventional velocity and depth measuring equipment using current meters, sounding devices or dilution techniques (Nordin and Richardson, 1971).

Spatial and temporal increments of collecting the field data are major components of the data collection program and should be carefully designed. The major factors to be considered include the tracer placing method, the hydraulic conditions of the water environment, the stability of waterway, the data analysis method, and the economical justification. In general, for a less stable waterway system, data collection should be more frequent.

2.5 ANALYSIS OF DATA

Field data collected from the tracer method include counting rates

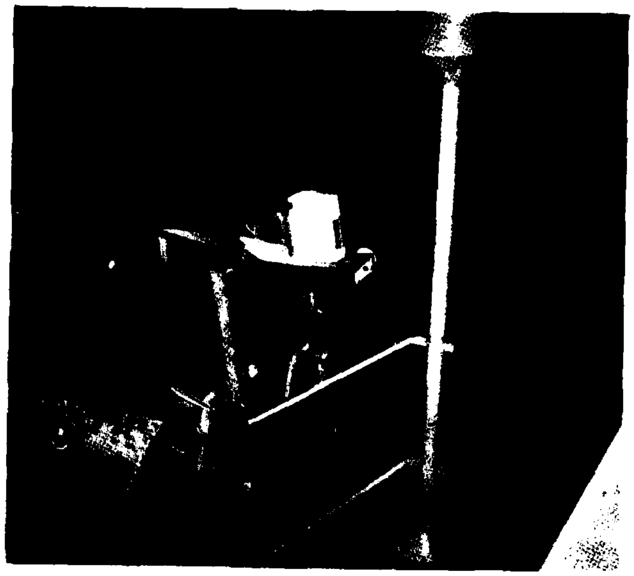


Fig. 2-5. The Dosing Apparatus
(after Sayre and Hubbell, 1965)

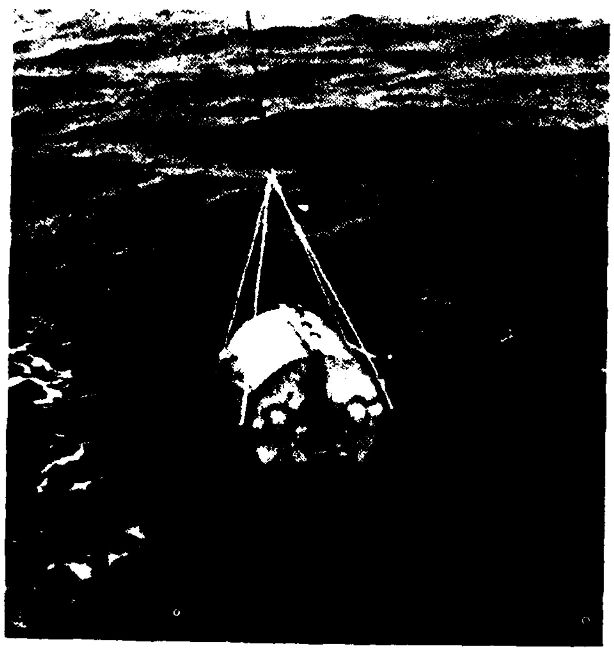


Fig. 2-6. Clamshell Device for Emplacing Tagged Sand
(after Duane and Judge, 1969)

of radioactive tracers (if radioactive tracing technique is used), video tapes recording the locations of tracer particles on the riverbed surface (if fluorescent tracing technique is used by effectively employing TV monitoring system), bed sample cores and the hydraulic conditions. The counting rates of radioactive tracers can be converted to sediment concentration using the calibration relation between the tracer concentration and counting rate, and corrected by considering the background radiation and isotope decay. The isotope decay can be corrected by the relation

$$I = I_o e^{-\lambda t} \tag{2.1}$$

where I is the recorded intensity in cpm, I_o is the initial intensity, λ is the decay constant given by $0.693/T_h$, t is the elapsed time and T_h is the half-life of the radioisotope. If stable-isotope tracers are used, the bed samples can be processed, neutron activated and the gamma ray spectra determined. From this data, the movement of sediment can be determined.

By using the fluorescent particles as the tracer, bed sample cores are required to count the fluorescent particles under the ultra-violet light. To simplify the counting procedure, a relation between the number of fluorescent particles on the surface of bed and the mean number per unit volume of bed can be derived from the calibration. The former information may be obtained from the underwater TV monitoring system. Then the tracer concentration can be determined from the calibration relation. An automatic counting system for analyzing bed samples is also available. The TR 25 system manufactured by Cambridge Instrument Co. can automatically determine concentration of tracers and measure particle sizes of a number of samples in a short period of time. For more information, one can contact Mr. Bryant Partridge in their San Francisco office.

Counting the fluorescent particles dyed by different colors that denote particle sizes, the transport of the various sediment size fraction can be determined.

Information derived from the field data can be utilized to determine the transport and dispersion of bed material. The bed-material discharge can be determined by: (1) the dilution method (or steady-dilution method), (2) time integration method, and (3) spatial-integration method.

In the steady-dilution method, a mixture with tracer concentration C_1 is injected continuously at position x_1 at a rate Q_T. The conservation of mass yields

$$Q_T C_1 = (Q_T + Q_s) C_2 \tag{2.2}$$

where C_2 is the measured concentration at a downstream station x_2 and Q_s is the sediment discharge of the stream. Equation (2.2) is based on the assumption that complete lateral mixing has occurred. If Q_T is much smaller than Q_s, the sediment discharge is given by

$$Q_s \simeq Q_T C_1/C_2 \tag{2.3}$$

Samples can be collected continuously at several points in the downstream cross section to determine an average C_2.

Equation (2.3) is only applicable under a relatively steady undirectional flow. In some estuary areas having multi-directional flow, this equation is no longer valid. Russell (1961) derived the following equation considering movement of bed material in two opposite directions. The drift rate is

$$Q_s = \frac{(p-q)}{t} \frac{m N_x}{C_x} \tag{2.4}$$

where p and q are the fraction of tracer particles moving to the two

opposite directions respectively, m/t is the rate of tracer injected, N_x is the theoretical concentration determined from a probabiltiy table, and C_x is the measured concentration at point x. The parameters p and q can be estimated by selecting values of p and q such that the theoretical concentration N_x best fits the measured tracer concentration. Equation (2.4) and other similar relations can be generalized to determine the sediment transport rate in multi-direction flow.

In the time-integration method, a weight, W, of traced material is introduced as an instantaneous point or line source and samples are collected continuously at a sampling station downstream to yield the concentration-time curve. Applying the conservation of mass, the sediment discharge Q_s can be determined from the relation:

$$W = Q_s \int_0^\infty C \, dt \tag{2.5}$$

where C is the concentration measured at the sampling station. In practice, it may be necessary to integrate in the transverse direction, so that C is the average concentration in the cross section. Furthermore, during the sampling period, the hydraulic conditions should be reasonably steady.

For the spatial-integration method, a quantity of tracer material is introduced as an instantaneous point or line source at position x_o at time t_o. The tracer cloud disperses downstream so that its centroid is at position $\overline{x}_1$ at time t_1, and $\overline{x}_2$, at time t_2. The velocity, V, of the tracer cloud is

$$V = \frac{\overline{x}_2 - \overline{x}_1}{t_2 - t_1} \tag{2.6}$$

and the sediment rate is then

$$Q_s = V\ d\ \gamma_s\ (1-\gamma)\ B \qquad (2.7)$$

where d is the mean depth of movement of the tracer material in the bed, determined from core samples or approximated by dune height of bed form, B is the channel width, γ_s is the specific weight of the bed material, and λ is porosity of the bed. The centroid position $\bar{x}$, is given by

$$\bar{x} = \frac{\int_o^\infty C\ x\ dx}{\int_o^\infty C\ dx} \qquad (2.8)$$

The concentration, C, is assumed to distribute uniformly in the cross-sectional area, Bd. Usually, complete vertical and lateral mixing is very difficult to obtain, and the position of the tracer cloud must be defined by the radioactive detection system (if radioactive tracers are used) or network of core samples (if fluorescent tracers or stable isotope tracers are used). An average concentration, $\bar{C}$, can then be determined and plotted versus position x to evaluate the integrals. Note that both the time integration and spatial-integration methods are total-recovery methods; that is, if no tracer material is lost, the area under the C versus x curve is constant for different values of t and the area under the concentration-time curves is a constant for various position, x, along the channel.

In all three methods, it is assumed that the properties of the tracer material are identical to the properties of the natural sediment, and that the amount of tracer material injected is small in comparison with the natural sediment transport rate. Experience with tracers in determining sediment discharge suggests that the steady-dilution should be used for flows with a flat bed and high transport rate, while the

spatial integration method is more applicable to low-veloctiy flows over a dune bed.

Another application of the tracer technique is to map the dispersion of bed material. This is especially useful in studying the movement of dredged material placed in a low flow area and in studying the movement of the contaminated sediment. By using the tracing technique, the dispersion of tracer particles can be traced to determine contours and dispersion rate of bed material.

Because the dispersion problem is important and the field study is laborious, a large number of theories have been developed to predict the dispersion of bed material and verified by using the results of tracer technique. Many deterministic models which relate the particle velocity to the tractive force have been developed by different investigators (see summary given by Bogardi, 1974). Newton's second law of motion: f = ma, was employed. These deterministic models might be sound if all particles at all time exercised a continuous motion on the alluvial bed.

However, the bed material movement does not behave in this manner. The particles move with random velocities, random step lengths and random moving periods. The particle rests with random resting periods, and in the dune bed case, with other particles deposited on top. All of these random features of the movement and the burial condition cannot be taken care of by deterministic models. Einstein (1937) was the first to treat this movement as a problem of probability of motion using stochastic models. Sayre (1968), Grigg (1969), Hung (1975), and other investigators developed different stochastic models in the past decade. Even though these existing models are still imperfect, all of them have contributed their share in constructing the foundation for, and paving the way toward a solution.

2.6 SUMMARY AND CONCLUSIONS

Sediment movement in natural waterways is an extremely complex phenomenon. The tracer method appears to be practically feasible and safe in study of the dispersion and transport of bed material. To successfully apply these methods to obtain useful information, the following factors should be considered: (1) the means for selecting and labeling the sediment tracer particles, (2) the amount of tracers to be used, (3) the method of introducing the tracer into the flow system, (4) the method of detecting tracers, and (5) reduction and interpretation of the collected data, and (6) cost of utilizing the method.

A number of tracers have been developed and successfully utilized. However, selection of tracers and quantities of tracer particles required in the measurement still mainly rely on experience. There has not been a comprehensive and systematic study of tracer methods. All existing tracer methods should be identified, assembled and evaluated. The most feasible methods could then be identified, categorized and hopefully, improved.

Because a field study of the transport and dispersion of the bed material is laborious and expensive, many researchers have attempted to develop other prediction methodologies. Stochastic models may be more suitable for studying bed material dispersion than deterministic models since the movement of bed particles is a random process. However, existing models are still not perfect. Also, there are empirical or theoretical coefficients involved in all models and the evaluation of these coefficients still rely on field and laboratory studies. Considerable research is required to add further knowledge in this important field.

Chapter 3

SELECTION OF TRACER METHODS

3.1 CRITERIA FOR SELECTION OF TRACER PARTICLES

Adoption of a certain tracer depends on the objective of the measurement, background flourescence and radiation level, hydraulic conditions, absorption characteristics of the media, safety, ease of measurement and cost. The use of flourescent tracers requires that physical samples of the bottom materials be secured and minutely examined in order to detect the presence of labeled particles. For study of a large area, the large number of samples resulting from survey of channel or oceanic floor would be unwieldy and expensive to analyze. One way of reducing the sampling effort for determining the distribution of tracer particles is to use underwater TV camera equipped with ultra violet light to examine the presence of tracer particles on the riverbed surface and then convert this information to concentration by using a rating relation. It is not clear at this point in time how the water turbidity may affect the sensitivity and accuracy of the underwater TV monitoring system. Field data indicate that water turbidity in the Upper Mississippi River varies from about 10 T.U. (turbidity units) at low flow to 100-200 T.U. at high flow. Therefore, utilization of the TV monitoring system should have no problem due to turbidity at low flow and intermediate flow but may have problems at high flow. Field or laboratory tests can be utilized to evaluate the effects. Flourescent tracer particles are relatively inexpensive and can be dyed into various colors to represent their sizes and sources. Then the movement of sediment size can be measured.

Radioactive tracers have the advantage that they can be detected by equipment at the site. The transport and dispersion of bed material in a large area can then be directly measured and monitored. However, it is still difficult to trace the movement of radioactive particles of different sizes. Duane and Judge (1969) attempted to study and select different isotopes which emit Gamma radiation with their energy peaks sufficiently separable to permit detector discrimination in the field. The results should help evaluate the transport of different sediment fractions. Another disadvantage of radioactive tracers is the possible damaging effect of radiation to the investigators and the extent to which the method can be utilized in public areas without the creation of a health hazard. Increased public concern over pollution and contamination of our natural waters and beaches may preclude the application of radioactive materials in areas that are frequented by the public.

Stable isotope tracers present no environmental hazards since they do not involve radioactivity until after the samples are collected and activated. Also, neutron activation provides a very sensitive tracing technique. However, clay particles cannot suitably be labeled with a stable isotope. Media, rich in monazite, xenotime and other heavy minerals, have potential problems of background interference. In addition, preparation of stable isotope tracers and sample analysis are more costly, and cannot be done on site.

After considering the important factors governing selection of tracers and analysis techniques, Table 3-1 was prepared to assist with selection. The "✓" symbol given in the table indicates that a particular tracer is favorable. Accuracy, safety and cost are considered in more detail

TABLE 3-1. Criteria for Selection of Tracers

Factors		Fluorescence Tracer	Radioactive Tracer	Stable-Isotopic Tracer
Study Time	Long	✓	✓	✓
	Short	✓	✓	✓
Study Area	Large	✓	✓	✓
	Small	✓	✓	✓
Background Interference	Fluorescence		✓	✓
	Radioactive	✓		✓
	Heavy Mineral	✓	✓	
Bed Material	Coarse (sand & gravel)	✓	✓	✓
	Fine (silt & clay)		✓	
Analysis Techniques	Off-site	✓	✓	✓
	On-site	✓	✓	
Public Safety		✓		✓
Cost		✓	✓	

in the following sections related to selection of proper tracers for tracking movement of dredged material disposed of in the Upper Mississippi River.

Since the detection system depends on the amount and distribution of the tracer particles, a minimum number of particles is required for statistical significance. Russell (1960) found that 10 counts of fluorescent tracers per square feet of bed surface provided satisfactory results. Krone (1960) indicated that a distribution of 3 radioactive tracer particles per square centimeters on the bed surface would provide an adequate number of tracer particles near the detector. Malone (1969)

and Boone and Slowey (1972) indicated a detection limit of about 3 or 4 sand grains of stable isotope tracers per 100,000 grains of untreated sediment. With the improvement of the stable isotope labeling technique and increased sensitivity of detection equipment, Leahy,et al.(1976) reported a detection limit ten times smaller. If the volume through which the tracer particles will be dispersed at the end of the measurement period is estimated, the total number of tracer particles required can be determined accordingly.

3.2 CONSIDERATION OF ACCURACY

The accuracy of the tracer methods mainly depends on the accuracy of tracer particle movement respresenting the movement of natural sediment and the ability of detecting the tracer particles. These factors rely on the hydraulic properties of trace particles, the activity of tracers, background interference and the sensitivity of detection equipment. In the following section, three types of tracers are discussed to evaluate their suitability for this monitoring program.

3.2.1 Fluorescent Tracers

To better simulate the properties of natural sediment and to produce a large amount of tracer materials, sand tracers can be produced by taking sand from the areas to be studied and coating each grain with a thin layer of fluorescent plastic such as Kiton Yellow, Bhodamine "B" extra 525%, Uvitex SWN. The resultant tracers can retain maximum brilliance when exposed to unfiltered UV tests equivalent to one-year natural weathering. The period of one-year may be a suitable monitoring period. The tagged tracer particles should be tested by examining their fall velocities, sizes and densities.to make certain that they simulate the natural sediments.

If the distribution of tracer particles through the bed is random, as the concentration of tracer particles increases, the relative distribution of the tracer particles tends to become more even. In statistical terms, the random variations in the number of particles in a given volume can be characterized by the coefficient of variation, or relative standard deviation. Because the variation in the number of tracer particles in a given volume follows the Poisson distribution, the coefficient reduces to $100/\sqrt{N}$, where N is the mean number of tracer particles in the given volume of bed material. The coefficient of variation for tracer distribution provides a statistical evaluation of accuracy.

The number of tracer particles required for a particular experiment can be determined by setting limits on the coefficient of variables and by precisely defining the given volume. Intuitively, the volume can be defined by the volume of each sample and N can be defined as the required number of tracer particles within the volume at the end of the experiment when the tracer particles are distributed over the entire test reach.

According to Russell (1960), 10 counts of fluorescent tracers per square foot of bed surface provided satisfactory results. If the particle size is 0.4 mm, then the number of particles occupying a square foot riverbed surface and a cubic foot of riverbed volume would be around 2.9×10^5 and 4.2×10^8, respectively. Assuming that the tracer particles are uniformly distributed in the riverbed, then the required number of particles per each cubic ft of river bed would be about $4.2 \times 10^8 \times 10/(2.9\times10^5)$, or about 1.4×10^4. This provides a concentration of bed material at the end of the experiment of about

33 ppm by volume which is the minimum tracer concentration required in the experiment. If the volume through which the tracer particles will be dispersed at the end of the measurement period is 1 mile long, 1,000 ft wide and 2 ft deep, the total number of tracer particles required is about 1.5×10^{11}, which weighs about 15 tons.

If a 3-in. diameter sampler was used to collect 2-ft cores, the surface area of the bed sample would be 1.57 sq. ft. Then there would be about 16 tracer particles shown on the sample surface if the estimated tracer concentration was correct. This would result in a coefficient of variance on the tracer concentration distribution of about 25%. If a underwater TV detection system having a practical range of 2 ft in diameter was used, the coefficient of variation would be around 15 percent.

3.2.2 Radioactive Tracers

The accuracy of the radioactive tracer technique increases as the level of radioactivity increases. The amount of radioactivity and number of tracer particles required for an experiment should be determined for desired accuracy.

The amount of radioactivity required for the experiment depends on: (1) the level of the background radiation, (2) the volume of sand throughout which the tracer particles would be dispersed, (3) the decay rate of the radionuclide, (4) the radioation-absorption characteristics of the media between the detector and the tracer particles, (5) the efficiency of the radiation detection system, and (6) the geometrical orientation of the detector to the tracer particles. Items 4-6 can be evaluated together by determining an overall sensitivity from calibration measurements with the equipment under conditions that simulated

the experimental environment. The overall sensitivity is defined as the counting rate due to a source uniformly distributed throughout an infinite volume to the specific activity. Sayre and Hubbell (1963) determined that the sensitivity for Iridium-192, Gold-198, and Cesium-137 were 9.15×10^5, 3.86×10^6 and 4.56×10^5 cpm/mc/ft^3(counts per minute per millicurie per cubic feet), respectively using a NaI scintillation detector.

If the sensitivity is determined, the amount of radioactivity, M in millicuries (mc) required for the experiment can be computed from:

$$M = \frac{(R_o - R_b)\ V\ \exp(0.693\ t/T)}{S} \tag{3.1}$$

in which $R_o - R_b$ is the minimum net counting rate over background, in counts per minute (cpm), that is required during the experiment for statistical significance, V is the estimated volume in cubic ft, through which the tracer particles will be dispersed at the end of the experiment, S is the overall sensitivity, t is the duration of the experiment and T is the half-life of the radionuclide.

Tracking of the bed material movement is a relatively long-term duration process. Therefore, tracers to be considered in this monitoring program require a relatively long half-life. After examining Table 2-1, tracers considered to have adequate half-life are Silver-110 (270 days), Iron-59 (45.1 days), Scadium-46 (84 days), and Iridium-192 (74 days). The required amount of activity for these tracers based on the following conditions and assumptions were computed from Eq. 3-1 and are given in Table 3.2:

(1) The duration of the experiment is 1 year.

(2) Assume a background counting rate of 200 cpm.

(3) Assume the sensitivity approximately equal to 1 x 10^6 cpm/ mc/ft^3.

(4) Consider a minimum net counting rate equal to one-third the background rate to be acceptable for the condition of a uniform distribution of tracer particles through the test reach (this results in a standard deviation value of ± 10% of the net signal).

Similar activities required for the experiment were determined from methods described by Kohl, et al. (1961).

TABLE 3.2 Amount of Activity

Tracer	Half-life (days)	Energy (mev)	Amount of Activity mc/ℓ
Silver-110	270	2.90	5.3×10^{-6}
Iron-59	45.1	1.10	5.8×10^{-4}
Scadium-46	84	1.12	4.3×10^{-5}
Iridium-192	74	0.90	6.5×10^{-5}

The number of tracer particles required for a study can be approximately determined on the basis of information reported by Krone (1957). According to Krone, a distribution of 3 tracer particles per square centimeter on the surface of the bed would provide an adequate number of tracer particles near the detector. By assuming that the tracer particles would be evenly distributed over the entire test reach at the end of the experiment and that one-half of the particles would be either lost or buried beyond the range of the detector, it was calculated that about 5.6 x 10^3 particles would be required in a 1 sq ft

surface area. Assuming that these particles are uniformly distributed to a depth of 2 ft, the particle population density would be 1.62 particles per cubic inch. If the tracer particles were uniformly dispersed in a river reach of 1 mile long, 1,000 ft wide and 2 ft deep, the required number of tracer particles would than be 3.0 x 10^{10} which weighs about 3 tons.

If a NaI scintillation counter with a thickness of NaI of 3 inches was used, the volume within the practical range of the dectector (around 5 inch diameter) would be around 144 cubic inches and about 233 tracer particles would be within the practical range. Thus the coefficient of variation of tracer distribution in a given volume would be around $100/\sqrt{233} = \pm 6.6$ percent, which is generally acceptable.

3.2.3 Stable Isotope Tracers

Malone (1969) and Boone and Slowey (1972) indicated a detection limit of about 3 or 4 sand grains of stable isotope tracers per 100,000 grains of untreated sediment. However, Leahy, et al (1976) reported a detection limit 10 times smaller. For this project, let us use a detection limit of 1 sand grain of stable isotope tracers per 100,000 grains of untreated sediment. If the volume through which the tracer particles will be dispensed at the end of the measurement period is 1 mile long, 1,000 ft wide and 2 ft deep, the total number of tracer praticles required is about 4.7 x 10^{10}, which weighs about 5 tons. The coefficient of variation for tracer distribution would be about 5% if a 3-in. diameter sampler was used to collect 2-ft core.

The sensitivity of the stable isotope method may be extended by increasing the amount of rare-earth label per unit weight of natural sand. Increasing the amount of rare-earth label tenfold, from the 1 mg/gm

level to the 10 mg/gm level, may give the desired detection limits but may also introduce other problems. The most important factor of such problems would be the alteration of the surface properties of the sand grains which would tend to affect the hydraulic behavior of the grains. Therefore the hydraulic properties of tagged tracer particles should be carefully examined.

3.2.4 Comparison of Accuracy of Tracer Methods

As described earlier, radioactive tracers would require the least amount of tracer particles and stable isotope tracers have the smallest coefficient of variance. These two types of tracers have the same order of accuracy, provided that the activities of radioisotope and stable isotope utilized for tagging tracers are sufficiently high. The accuracy of fluorescent tracers can be improved if the number of tracer particles is increased. However, the problem related to photolysis and alteration of hydraulic properties of fluorescent tracers should be carefully examined before its usage. An unfiltered UV test can be utilized to evaluate the photolysis effects on fluorescent tracers. Since the action of ultraviolet light decreases with an increase in water depth, it is expected that photolysis should present no significant problems when applying the fluorescent tracers in the Upper Mississippi River. To examine the alteration of hydraulic properties of tracer particles, their sizes and fall velocities can be determined and compared with those of natural sediment.

3.3 SAFETY CONSIDERATIONS

As described earlier, the fluorescent tracers in general do not contaminate the riverbed. The stable isotope tracers are not radioactive until they are neutron activated. Therefore, these two tracers

are safe and will not induce any significant adverse impacts on river environment. Conversely, the application of radioactive tracers should maximize safety.

Field safety procedures of using radioactive tracers basically follow such common-sense rules as allowing little if any handling of the treated radioactive material, being overcautious with shielding procedures, not exposing the treated material to the air unless absolutely necessary, the wearing of film badges, and the constant monitoring of the site and equipment with counting devices.

Calculations were made to determine the maximum allowable activity on the tracer particles presented neither an internal nor an external radiation hazard. Internal exposure is that which occurs when radioactive material is inhaled or ingested. External exposure is that which occurs when the body is subjected to direct radiation such as from a nuclear blast or immersion in a cloud of radioactive gas. For the calculations, two different basic assumptions were made. The first assumption was that all of the activity would be removed from the tracer particles as soon as they were introduced into the water. With this assumption, computations showed that the activity would be diluted to the maximum permissible concentration for (mpc) for Silver-110, Iron-59, Scadium-46 and Iridium-192 for water flowing past the dosing section at a rate of 15,000 cfs in about 3, 3,840, 13 and 19 minutes, respectively (see Table 3-3). Inasmuch as the dosing operation during dredging would usually require more than hours, the mpc would not be exceeded except when using Iron-59. The second assumption was that all of the activity would remain on the particles. Based on this assumption, note that the activity on the tracer particles would disperse within the bed material to

TABLE 3.3 Safety Consideration of Radioactive Tracers

Tracer	Amount of Activity* (ci)	MPC_w**	Dilution Time† (min)	Displacement Length †† (ft)
Silver-110	1.6	20,000	3	1,440
Iron-59	173.0	50,000	3,840	1,800,000
Scadium-46	12.8	40,000	13	5,700
Iridium-192	19.3	40,000	19	8,500

* Amount of activity required for the experiment if at the end of the experiment (1 year) the tracer is uniformly distributed in a reach of 1 mile long, 1,000 ft wide and 2 ft deep.

** Maximum permissible concentration due to continuous lifetime exposure in 10^{-12} cury per liter of water recommended by the National Committee on Radiation Protection (U.S. Department of Commerce, 1959).

† Computed based on a discharge of 15,000 cfs (low flow discharge in the Upper Mississippi River).

†† Assume that the placed area is 1,000 ft wide and 2 ft deep.

a low concentration approximately equal to the maximum permissible concentration for drinking water, if it is assumed that particles are uniformly distributed through a disposal area within the test reach as identified in Table 3.3. It can be seen, with the exception of Silver-110, the computed length for placing the tracers Iron-59, Scadium-46 and Iridium-192 are not practical. However, these criteria provide a wide safety margin. Large quantities of bed material, unlike water, would never be ingested. Also with the second assumption, the tracer particles conceivably could represent an external radiation hazard. However, the depth of water in the stream can afford more than adequate shielding at all times, since the gamma emission energy usually attenuates more than 50% beyond a distance of 3 inches. Therefore, the length of disposed tracer particles can be much less than those shown in Table 3-3 without causing safety problems.

Considering the amount of radioactive activity required for a large scale long-term study, application of radioactive tracers requires extreme caution. Even if a radioactive tracer such as Silver-110 can be safely utilized, the present attitude towards nuclear safety may preclude the application of radioactive tracers in a public water course. It is then clear that when utilizing radioactive tracers public acceptance, but neither public health nor environmental damage, is usually a problem.

3.4 COST CONSIDERATIONS

The major cost factors when selecting a tracer method should consider: (1) cost of tracer, (2) cost of its transport, (3) cost of measurements, and (4) interpretation of data. For a large-scale long-term study required for tracking the movement of dredged material, it is necessary to prepare a large volume of tracer particles. Therefore, the cost of tracers becomes the primary economic consideration. Fluorescent

tracers are relatively inexpensive compared to radioactive tracers and stable isotope tracers. The only known economic way to prepare large quantities of radioactive tracer particles is by absorption and baking. Irradiation is not a feasible way of preparing large amounts of radioactive tracers because of its cost. Rare-earth isotopes for tagging stable tracers can be quite expensive.

For fluorescent tracers and stable isotope tracers, the cost of transportation is very minor. Tracers emitting gamma rays give rise to additional cost because of the need for protection against radiation. Radioactive tracers are often carried to the investigation site in special vehicles.

The most economical measurement system is obviously the direct one (in situ). The measurement cost decreases considerably if the apparatus is able to continually register the measured parameters. Measurements are interpreted according to the precision and the sensitivity of the apparatus used. The lower the sensitivity threshold, the lower the activity used and hence the determination cost.

Because each tracer experiment presents different problems that cannot be handled in a generalized fashion, only rough costs were estimated here. For the purpose of comparison, costs for conducting different tracer methods applied to the same experiment were estimated. This experimental design has the following features:

1. The experiment would last a year and the tracer particles would be uniformly distributed in a river reach 1 mile long, 1,000 ft wide and 2 ft deep at the end of the experiment.

2. If an off-site data analysis method was used, the sampling points for collecting bed material core samples would be located in

the study area with a transverse interval 50 ft and a longitudinal interval of 500 ft. In this way, about 200 bed samples would be required for laboratory analysis at each sampling period. Assume that six sampling periods would be required in the experiment.

3. If an in-situ data collection is used, detection equipment can be towed transversely at a longitudinal increment of 500 ft.

With these bases, the cost for conducting different tracer studies were roughly estimated and are given in Table 3-4. The fluorescent tracer is usually the cheapest tracer and the stable isotope tracer is usually the most expensive tracer.

3.5 SELECTION OF TRACER METHOD

After considering various factors, particularly those factors on accuracy, safety and cost for selection of tracer methods, it is found that the fluorescent tracer method using a TV monitoring system is the most suitable method for tracing the movement of dredged material disposed of on thalweg or along river banks, provided that the water turbidity does not significantly affect the efficiency and accuracy of the TV monitoring system and the fluorescent tracer particles retain their brilliance to the end of the experiment. In the Upper Mississippi River, water turbidity should not cause significant problems except potentially at high flow. A number of fluorescent tracers have demonstrated the ability of retaining brilliance after more than a sampling season (3-6 months). Radioactive tracer is more accurate and easier to detect; however, the initial costs of tagging tracer particles are more expensive and it may have safety problems mostly due to public attitude. The stable isotope tracer method is more accurate than the fluorescent tracer method but it is also more expensive.

TABLE 3.4 Rough Cost Estimates of Tracer Methods

Tracer	Tagging Solution	Cost of Tracer		Data Collection		Sample and Data Analysis		TOTAL COST
		Unit Cost	Total	Unit	Total	Unit	Total	
Fluorescein	Rhodamine "B" and similar dyes	$0.4/lb of tracer including tagging cost	$12,000	6 samples per hour @ $50/hr plus equipment cost, travel etc.	$20,000	5 samples per hour @ $30/hr	$20,000	$52,000
Radioisotope	Scadium-46*	$235/vial (25 ml) plus tagging cost	$130,000	--	$10,000	--	$10,000	$150,000
	Iridium-192**	$1/mc plus tagging cost	$30,000					$50,000
	Silver-110***	$25/mc plus tagging cost	$50,000					$70,000
Stable Isotope	Iridium-191†	$6/lb of tracer	$60,000	--	$20,000	--	$40,000	$120,000
	Dysprosium-164††	$5/lb of tracer	$50,000					$110,000

* Unit price quoted by New England Nuclear, Inc., Boston, Massachusetts.
** Price as of October 1, 1979, quoted by Oak Ridge National Laboratory
*** Unit price quoted by Amersham Corporation, Arlington Heights, Illinois
† After Leahy, et al. (1976)
†† After Boone and Slowey (1972)

The accuracy of the fluorescent tracer method can be improved by increasing the amount of tracer particles. Doubling the amount of tracer particles will reduce the coefficient of variation from 15-25 percent to 10-15 percent. Its ability of tracking the movement of tracer particles in situ is very useful in improving the effectiveness of a data collection program. For a large-scale study as such, it is adequate to test various methods of tagging sediment or to select a method which has been proven applicable to a similar study to insure the ability of detecting tracer particles during the entire study period.

Chapter 4

DESIGN OF THE DEMONSTRATION PROJECT

4.1 SELECTION OF STUDY SITES

Based on the knowledge obtained from mathematical modeling of Pools 24, 25 and 26 (Simons, et al., 1975) and modeling of Pools 5 through 8 in the Upper Mississippi River (Simons, et al., 1980), it is found that a suitable thalweg site for placing the dredged material should have the following characteristics:

1. The thalweg disposal site should be within the practical range of the dredging site so that the dredged material can be transported to the disposal site without excessive effort.

2. To avoid increase in dredging quantities downstream of the disposal site, no severe dredging site should be within 2 miles downstream of the disposal site.

3. To avoid significant increase in sediment entering side channels and backwater areas, no side channels and backwater areas should be within 1 mile downstream of the disposal site.

Based on these criteria, the river reaches suitable and potentially unsuitable for thalweg disposal were identified in Table 4.1 from a preliminary analysis of dredging records and river geomorphology. The dredging quantities between Year 1945 and 1974 were plotted by location to the nearest river mile in Figs. 4.1 through 4.4. Also, indicated in these figures are the locations of the thirteen locks and dams and tributary locations. In addition, the general morphologic character of the river at a given location in terms of pools, crossings, straight reaches, divided reaches and wide reaches is included.

TABLE 4.1. Selection of Disposal Sites

L.&D.	River Mile	Description of Reach	Suitability of Thalweg Disposal
10	615.1	Heavy dredging in divided channel	UF
	603.0	Wide channel reach with negligible dredging	F
11	583.0	Minor dredging in divided channel	UF
	580.5	Narrow channel reach with negligible dredging	F
	578.0	Divided channel with negligible dredging	M
12	556.7	Divided channel with moderate dredging	UF
	549.0	Divided channel with moderate dredging	M
	539.0	Straight channel with negligible dredging	F
	535.0	Wide channel with moderate dredging	M
13	522.5	Divided channel with heavy dredging	UF
	514.0	Straight channel with negligible dredging	F
	511.0	Divided channel with moderate dredging	UF
	504.0	Straight channel with negligible dredging	F
	496.0	Divided channel with heavy dredging	UF
14	493.3	Straight and divided channel with minor dredging	M
	490.0	Straight and divided channel with negligible dredging	M
	486.0	Divided channel with minor dredging	M
15	482.9	Straight channel with negligible dredging	F
	476.5	Divided channel with minor dredging	M
16	457.2	— —	—
17	437.1	Straight and divided reach with heavy dredging	UF
	419.0	Straight and wide channel with minor dredging	M
18	410.5	Divided channel with heavy dredging	UF
	405.0	Divided channel with heavy dredging	UF
	394.0	Wide and straight channel with minor dredging	M
	390.0	Wide channel with negligible dredging	F
19	364.2	Straight and divided channel with negligible dredging	M
	359.0	Divided channel with heavy dredging	UF
	349.0	Divided channel with minor dredging	M
20	343.2	Divided channel with minor dredging	M
	339.0	Divided channel with heavy dredging	UF

TABLE 4.1 (continued)

L.& D.	River Mile	Description of Reach	Suitability* of Thalweg Disposal
	334.0	Divided channel with heavy dredging	UF
	332.0	Straight channel with minor dredging	M
	329.0	Divided channel with heavy dredging	UF
	327.0	Straight channel with minor dredging	M
21	324.9	Straight channel with minor dredging	M
	321.0	Divided channel with heavy dredging	UF
	312.0	Wide channel with negligible dredging	F
	303.0	Wide channel with minor dredging	M
22	301.2		

*F: Favorable; M: Marginal, UF: Unfavorable thalweg disposal reach

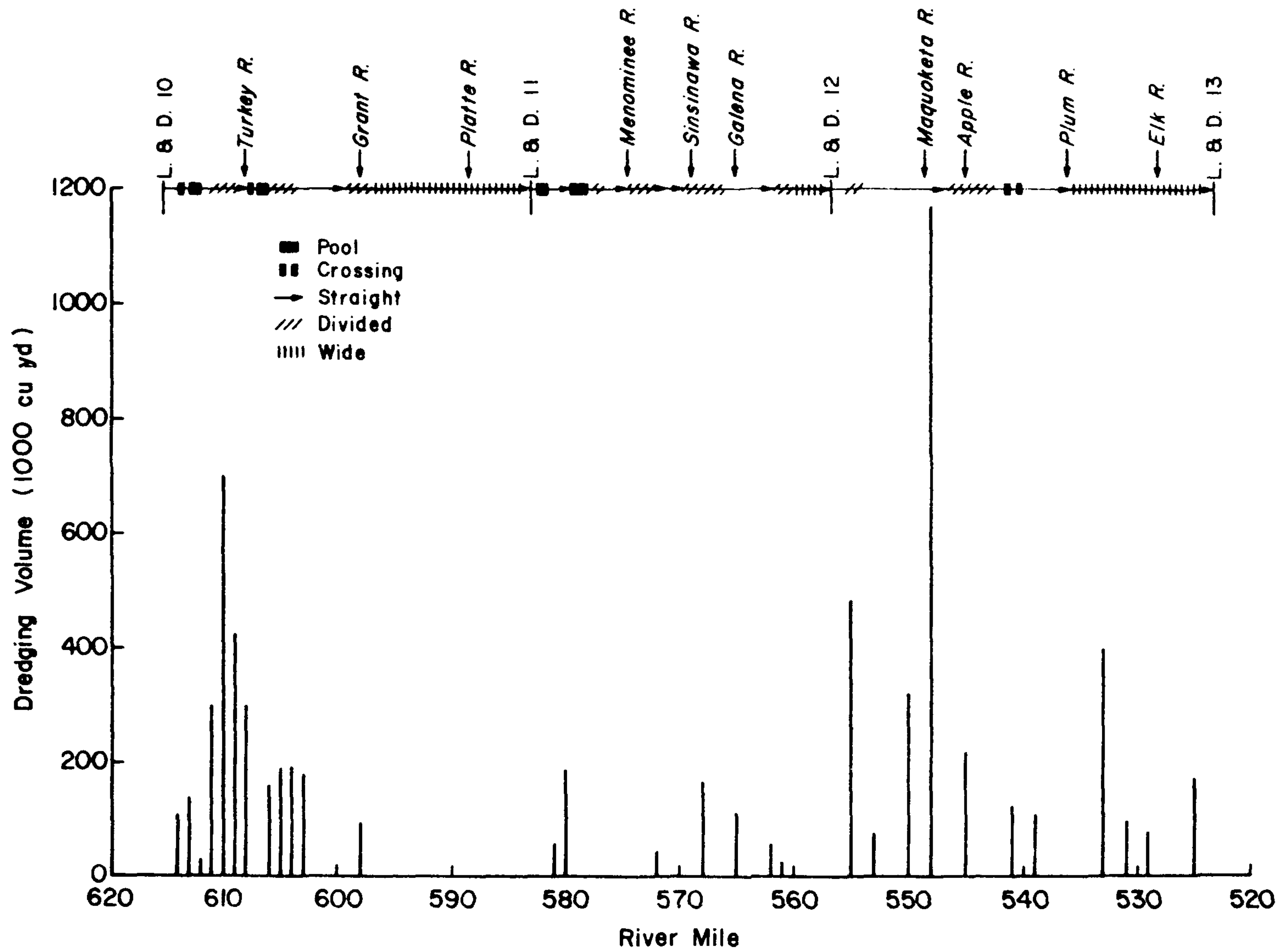


Fig. 4.1. Dredging Quantities by Locations in Pools 11, 12 and 13, Upper Mississippi River (Year 1945 - 1974)

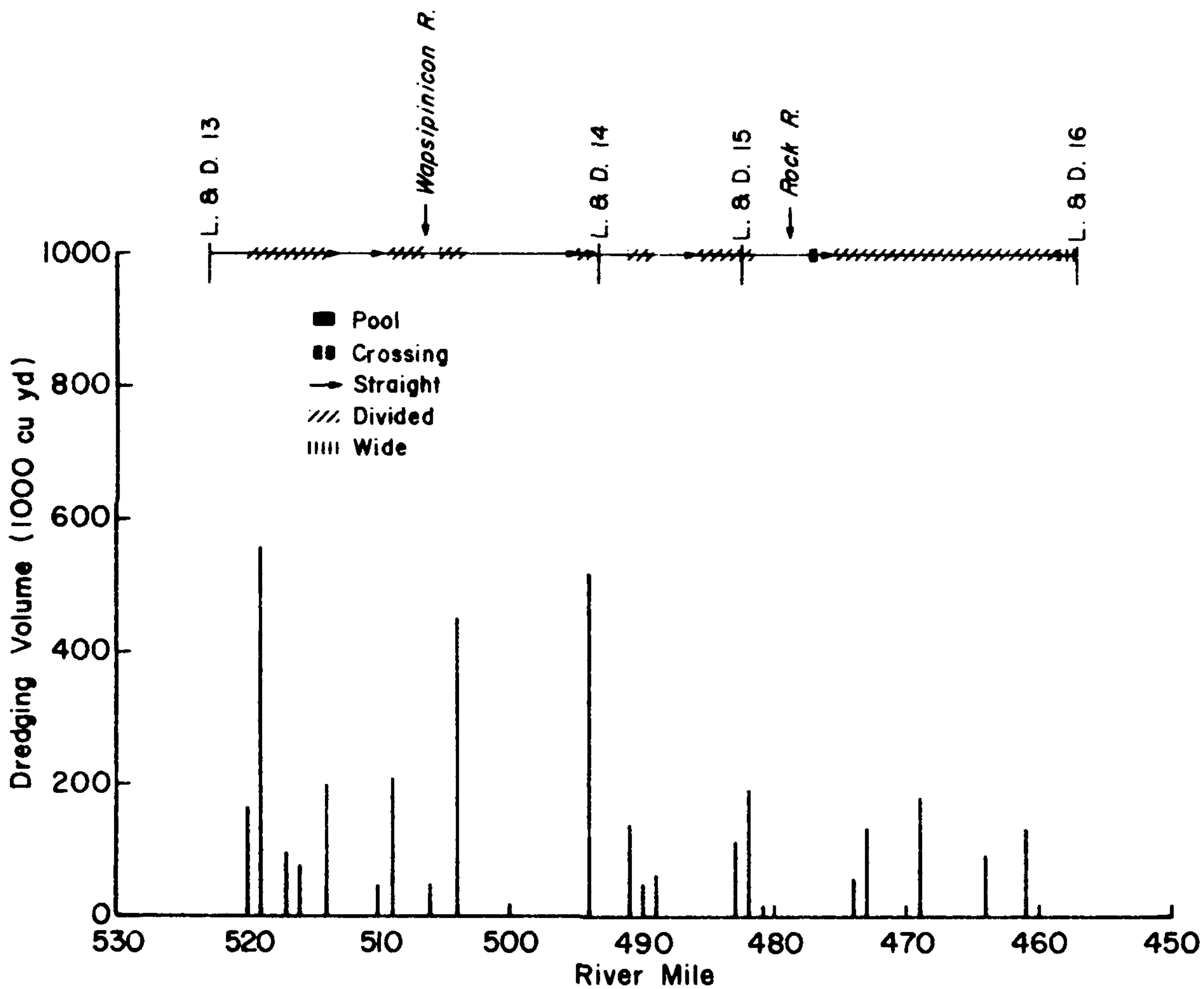


Fig. 4.2. Dredging Quantities by Locations in Pools 14, 15 and 16, Upper Mississippi River (Year 1945 - 1974)

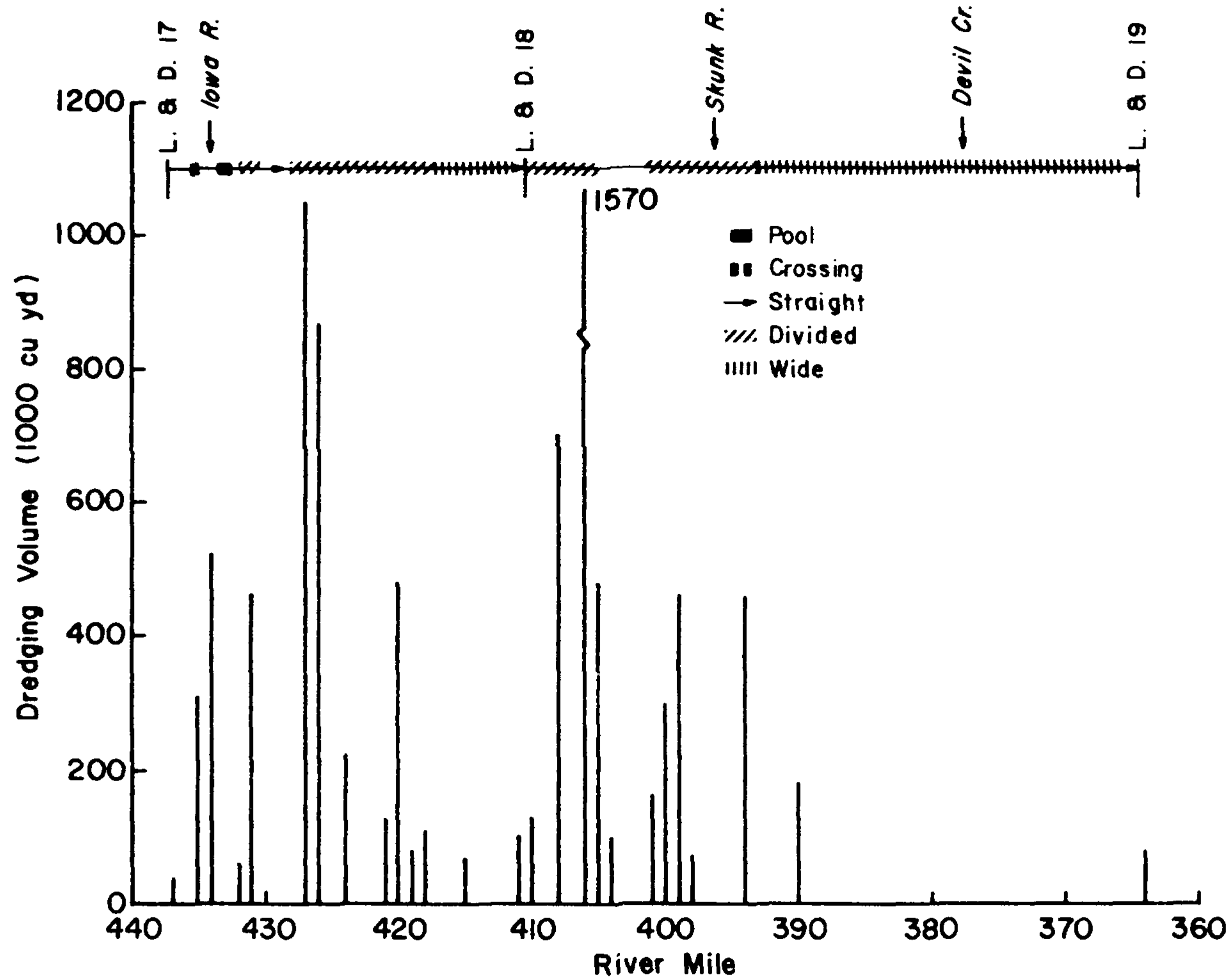


Fig. 4.3. Dredging Quantities by Locations in Pools 18 and 19, Upper Mississippi River (Year 1945 - 1974)

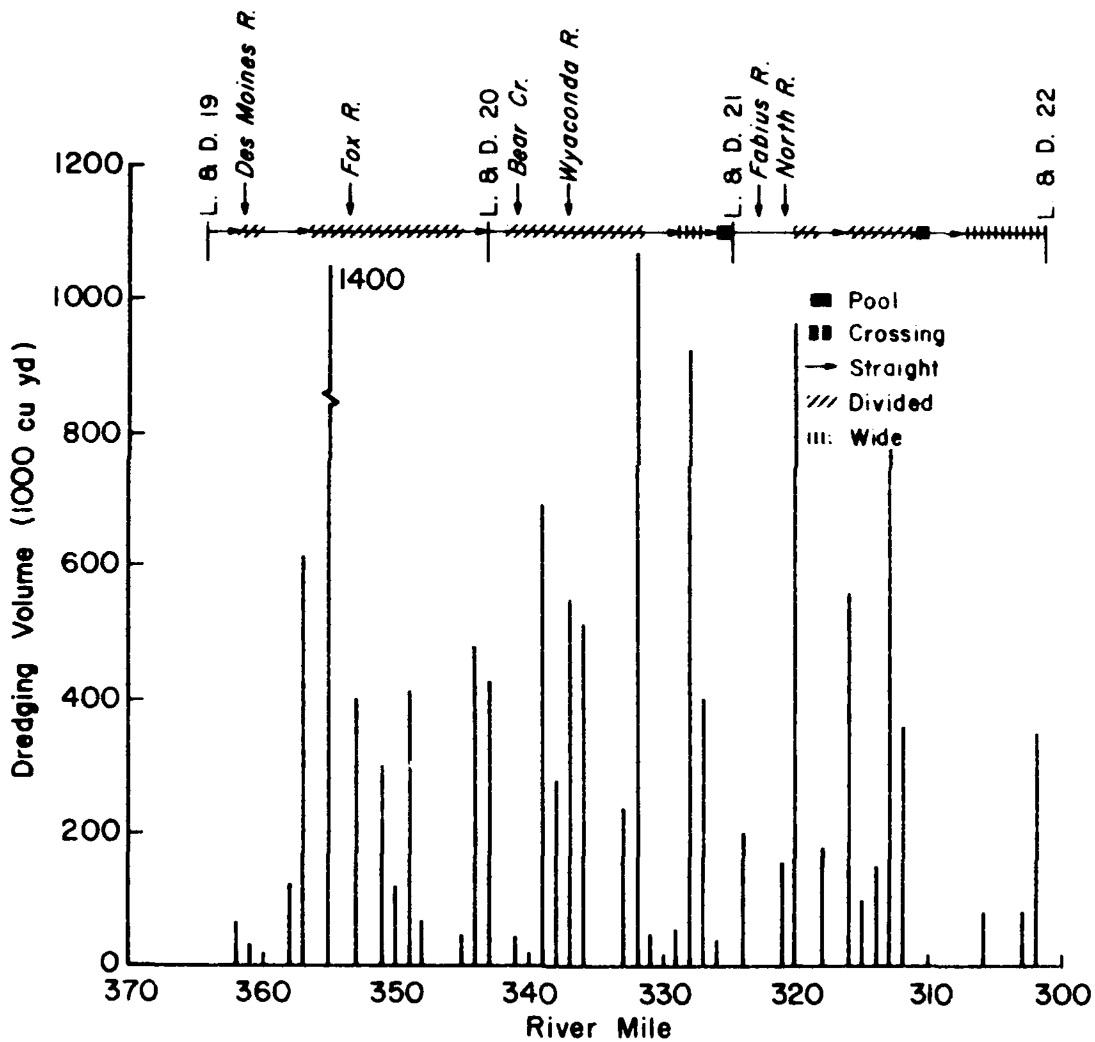


Fig. 4.4. Dredging Quantities by Locations in Pools 20, 21 and 22, Upper Mississippi River (Year 1945 - 1974)

It is found that the Maquoketa River in Pool 13, the Iowa River in Pool 18, the Skunk River in Pool 19, the Des Moines River in Pool 20, the Wyaconda River in Pool 21 and the North River in Pool 22 are significant sediment contributors. The most serious dredging problems occur in straight reaches which are located immediately downstream of a tributary that carries heavy sediment load and which are divided by alluvial islands. In general, river reaches requiring heavy dredging are considered as unfavorable reaches for thalweg dredging. Conversely river reaches requiring negligible dredging are considered as favorable reaches. A river reach with divided flow is considered no better than marginal for thalweg disposal.

It should be pointed out that the criteria described earlier and disposal reaches selected in Table 4.1 were derived based on a preliminary analysis of dredging records and river geomorphology and in some cases could be too conservative. These preliminary results should be evaluated and refined from the outcomes of the demonstration program and from a more thorough geomorphic study. It is possible that these reaches identified to be marginal or unfavorable for thalweg dredging in Table 4.1 may turn out to be feasible. A mathematical model study will also be very useful in developing criteria suitable for selecting thalweg disposal sites.

In order to have a viable demonstration project, the following parameters should be considered in the selection of study sites:

1. Since most dredging occurs in divided reaches, it must be proven or disproven if thalweg disposal will be acceptable in divided reaches from hydraulic and biological viewpoints.

2. Frequent or heavy dredging areas (reaches) are the ones with historic disposal site problems and the theories need to be proven or disproven in these areas as to hydraulic suitability and impacts on dredging requirements downstream.

3. If the theories of crossings and pools, storage and scour, and the fact that most of the bed material, being heavy, will remain in the main channel or major sand substrate chute channels, cannot be proven to be true, then thalweg disposal will not be a viable alternative.

4. In order to prove or disprove the above viewpoints, studies will be required for comparison at favorable and unfavorable sites.

After examining dredging records, parameters described above and sediment transport theories, the following sites are considered suitable for the thalweg disposal demonstration project:

1. The reach near the dredging site at river mile 406. This site has been heavily dredged (14 times from year 1945 to 1974 for a total dredging volume of 1,570,000 cubic yards). Immediately downstream of river mile 405 is a straight reach to about river mile 402. Downstream of this straight reach is a divided channel reach containing a large side channel named Shokokon Slough. This reach is classified as an unfavorable reach in Table 4.1. It will provide useful information to find out how the bed materials, being dredged and disposed in a straight reach, move into a divided channel reach having a large side channel. Similar reaches exist in the Upper Mississippi River within Rock Island District.

2. The reach near the dredging site at river mile 355. This site has been heavily dredged (12 times from year 1945 to 1974 for a total dredging volume of 1,400,000 cubic yards). The reach is classified as an unfavorable reach in Table 4.1. Downstream of this reach are several chute channels of different size. It will provide useful information to determine the amount of thalweg disposed material that is transported into these chute channels.

3. The reach near the dredging site at river mile 332. This site has been dredged 10 times from 1945 to 1974 yielding a total dredging volume of 1,070,000 cubic yards. Downstream of this reach is a 4-mile long undivided straight reach followed by a 3-mile long bend at the upstream end of Lock and Dam No. 21. The reach is classified as a marginal reach in Table 4.1 mainly because of possible increases in dredging requirements near river mile 327-328. It will provide useful information to find out how the thalweg disposed material moves in an undivided reach and how it affects downstream dredging cuts.

The final selection of disposal sites for the demonstration program should be determined by the Rock Island District in consultation with Colorado State University and other interested agencies and organizations.

4.2 PROPOSED TRACER METHOD

As discussed in Chapter 3, a fluorescent tracer method is the most suitable method for monitoring the dredged material disposed of in the Upper Mississippi main channel, provided that the brilliance of tracer particles can be retained throughout the monitoring period of the study. From the results of mathematical model studies, it was found that a sand bar formed by the dredged material placed on the thalweg would be washed away and the riverbed profile one year after the thalweg disposal would approach the natural river bed profile. A thalweg disposal conducted in Pool 4 in the Upper Mississippi River confirmed this finding. Therefore, a study period of one year is considered as a suitable monitoring time period. In the following sections, the amount of material required for tracing, source of tracer particles to be tagged, method and life expectancy of tagged material, detection equipment, field procedure, and potential impacts on local area are described.

4.2.1 Amount and Source of Tracer Particles

As discussed in Section 3.2.1, the amount of fluorescent tracer particles required for tracking the movement of dredged material disposed in the thalweg is about 15 tons if the quantities of dredged material is less than 350,000 cubic yards. If the dredging quantity is larger than 350,000 cubic yards, the additional amount of tracer particles can be determined by using a tracer concentration of 33 ppm by volume. This considers that an additional volume of bed material of about 50,000 cubic yards is transported to the study reach riverbed by flow. This amount of tracer particles mixed with disposed material would result in a coefficient of variance on the tracer concentration distribution equal to about 15 percent. These statistics indicate that the movement of tracer particles can illustrate the movement of major portion of disposed material no more than 15% in deviation, provided that the hydraulics properties of tracer particles are comparable to those of nautral sediment. If the amount of tracer particles was increased to 21 tons, then the coefficient of variance would be decreased to about 10%. Because of the large amount of tracer particles required in the monitoring program, natural bed material presented on the riverbed of the proposed dredging sites is an adequate source of materials to be tagged as tracers.

4.2.2 Labeling and Life Expectancy of Tagged Material

Sand tracers can be produced by taking bed material from the study areas to be dredged and coating each grain with a thin layer of fluorescent plastic. One method that has been successfully utilized to tag a large volume of sand is described below:

1. Spread the bed materials and let them dry (1-3 days).

2. Prepare tagging solution by mixing 2 pints of dye, 2 pints of vinyl plastic and 1 gallon of acetone solution in a concrete mixer to form fluorescent dye solution. This amount is sufficient to tag about 600 pounds of bed material. A larger amount of bed materials can be tagged at one time using a proportionally larger volume of dye solution. The AX series of dye (AX11--pink, AX15--orange, A19--blue and at least 9 more) manufactured by Day Glo Color Corporation, Cleveland, Ohio (phone: 216-391-7070), have been used to dye bed materials. Vinyl plastic VAGH manufactured by Union Carbide Corporation, South Charleston, West Virginia, has been used. New products may now be available. Dye costs about $200 for a 50-pound bag and vinyl plastic cost is a little cheaper. Mr. William Emmett from the U.S. Geological Survey used about 15 pounds of dye, 15 pounds of vinyl plastic and 80 gallons of acetone for tagging 1,800 kg of sand. Therefore to tag 15 tons of sand, about 150 pounds of dye, 150 pounds of vinyl plastic and 800 gallons of acetone are required.

3. Mix bed materials with the dye solution in a concrete mixer for about 30 minutes. Because of the fast evaporation of acetone solution during mixing tagged particles will not stick together and will come out dry.

The tagged tracer particles should be tested to compare their hydraulic properties with the natural sediment. The most important factor is the fall velocity of the particles. Tracer particles will move in similar fashion to that of the natural sediment if they have the same fall velocity even though their sizes and densities may be slightly different. The fall velocities and size distributions of natural and tagged particles can be determined using a fall velocity column and/or a sieve analysis respectively. Since the median size of

bed materials in the Upper Mississippi River is about 0.4-0.5 mm, a set of sieves including U.S. Standard sieves No. 18 (1 mm), No. 35 (0.5 mm), No. 60 (0.25mm), No. 120 (0.125 mm), No. 230 (0.062 mm), and some sieves in between, should provide the dize distributions. It is expected that the hydraulic properties of tagged particles should be quite similar to those of natural particles.

For this demonstration project, background fluorescein at the study site should be investigated. Suitable dye can then be selected to minimize background interference. Also the tagged materials should be tested to verify that their life expectancy is at least one year. The tagged material using the procedure described earlier was used in a shallow stream and showed no significant loss of fluorescence after a flood season of approximately 3 months. Since the fluorescence deteriorates with light and the flow depth in the stream is much shallower than that in the Upper Mississippi River, the fluorescence of tracers should last more than 1 year.

4.2.3 Detection Equipment

For this demonstration study, it is proposed that an underwater TV monitoring system equipped with ultra-violet light be used to photograph riverbed surface for later counting of tracer particles in the laboratory. Also, some bed-material samples should be collected to determine the relation between the number of tracers counted on the riverbed surface by the TV monitoring system and tracer concentration. In addition, a sonic depth sounder can be mounted on a survey boat to measure bed-surface profiles for back-up information. There is some concern that water turbidity in the Upper Mississippi River may affect the efficiency and accuracy of the proposed underwater TV monitoring system. Since the TV

monitoring system is still in an experimental stage, it is not clear at this point in time how the water turbidity may affect its performance. Field data indicate that water turbidity in the Upper Mississippi River varies from about 10 T.U. (turbidity units) at low flow to 100-200 T.U. at high flow. Therefore utilization of the TV monitoring system should not experience any problems due to turbidity at low and intermediate flows, but turbidity may be a problem at high flow. Some laboratory or field tests can be utilized to evaluate possible effects.

With this TV monitoring system, an experienced operator can better define the sampling zone and make necessary adjustments to establish a more effective sampling program and to obtain more meaningful monitoring results.

4.2.4 Field Dosing Procedure

Two major modifications to hydraulic dredge equipment should be made:

1. Modification of the transport pipeline for mixing tracer particles with dredged material before the dredged material is transported to the disposal site.

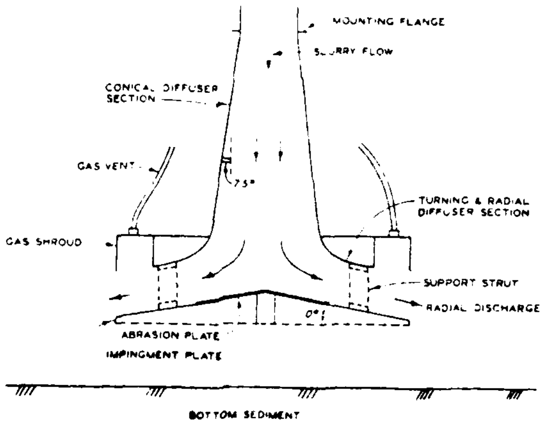
2. Modification to the pipeline discharge point for controlling the dispersion of dredged material slurry at open-water pipeline disposal operation.

For the first modification, a funnel tube with adequate valve controls can be connected to the transport pipeline upstream of the pump. Tracer particles can be fed through the funnel tube into the pipeline at an adequate rate to completely utilize the amount of tracer particles prepared for the study (say, 15 tons). The turbulence generated by the pump ensures uniform mixing of the tracer particles with

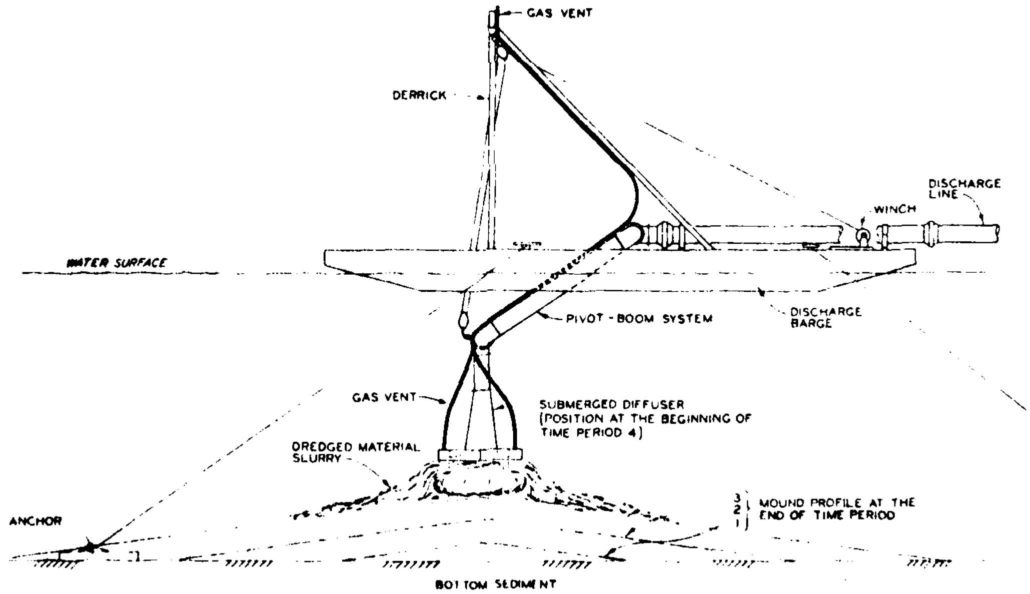
the dredged material. Another method for mixing tracer particles with dredged material is by first dumping the tracer particles evenly on the site to be dredged. Then the dredging operation will automatically do the mixing. One potential problem of this latter method is the possibility of nonuniform mixing.

To obtain a successful thalweg disposal operation, it is essential that the dredged material can be placed on the disposal site evenly, according to a predetermined pattern. The pattern of dredged material disposal is apparently controlled by the configuration of the pipeline at the discharge point as well as the angle and height of the discharge relative to the water surface (for above water discharge) or bottom (for submerged discharge). The simple open-ended pipeline, discharging above and parallel to the water surface, will maximize the dispersion of the slurry throughout the water column and produce a relatively thin, but widespread, sediment layer. In water depth in excess of 6 ft, the dispersion of the material in the water column can be decreased by vertically discharging the slurry through a 90-degree elbow at a depth of 1.5 to 3 ft below the water surface. Since most of the bed material in the Upper Mississippi main channel is sand, the increased turbidity and suspended load during the dredging operation will rapidly diminish in a short period of time.

According to Barnard (1978), most water-column turbidity can be eliminated by using a submerged diffuser system at the end of the pipeline to reduce the velocity and turbulence associated with the discharge slurry (see Fig. 4.5). This is accomplished by routing the flow through a vertically oriented, 15-degree axial diffuser with a cross-sectional area ratio of 4:1, followed by a combined turning and radial diffuser



(a) Submerged diffuser



(b) Submerged diffuser system, including the diffuser and discharge barge

Fig. 4.5 Submerged Diffuser System (after Barnard, 1978)

section that increases the overall area ratio to 16:1. Therefore, the flow velocity of the slurry prior to discharge is reduced by a factor of 16, yet the dredge discharge rate is not affected in any way by the diffuser. The conical and turning/radial diffuser sections are joined to form the diffuser assembly, which is flange mounted to the discharge pipeline. An abrasion-resistant impingement plate is supported from the diffuser assembly by 4 to 6 struts. The parallel conical surfaces of the radial diffuser and impingement plate slope downward at an angle of 10 degrees from the horizontal so that stones and debris can roll down the sloped surface and automatically clear the diffuser. The radial discharge area of the diffuser can be adjusted by changing the length of the struts supporting the impingement plate. In this manner both the thickness and velocity of the discharged slurry can be controlled. The strut length, which determines not only the slurry discharge velocity, but also the maximum diameter of an object that will pass through the diffuser, should be approximately five-sixths of the pipe diameter. Since the gas content of bottom sediment is often high (e.g., 5 to 30 percent of the in situ volume), the diffuser is also equipped with a gas collection shroud around the circumference of the radial diffuser section to trap any sediment-covered gas bubbles before the slurry is discharged. The gas is vented to the atmosphere through a hose extending from the shroud to the top of the derrick. The diffuser for an 18-inch pipeline is approximately 7.9 ft tall from impingement plate to mounting flange and 7.9 ft in diameter at its base, according to the original design.

The submerged diffuser system also maximizes the mounding tendency of the dredged material, thereby minimizing its areal coverage over the

disposal area to establish better control of the disposal pattern. Table 4.2 shows a typical schedule for adjusting the height of diffuser above the bottom for several different discharge pipeline sizes. The mount configuration at the end of each time period is shown in Fig. 4.5.

It is recommended that a submerged diffuser as shown in Fig. 4.5 be attached to the pipeline outlet to discharge dredged material at the disposal site for this demonstration project if it is economically feasible and timely. The disposal operation schedule can be determined based on the information given in Table 4.2. To simplify the operation and reduce the costs, it is possible to just use a 90-degree elbow at a depth of about 3 ft below the water surface to discharge dredged material. The disposed slurry pattern may not be as good as that obtained by using the submerged diffuser, but may be adequate. A discharge barge should be used in conjunction with the diffusers to provide both support and the capability for lowering the diffuser to within 3 ft of the bottom at the beginning of the disposal operation and raising it as required. The barge also provides a platform for the diffuser while it is being adjusted, serviced, or moved to a new site.

4.2.5 Potential Impacts

The fluorescent tracer particles proposed in this study are nontoxic and therefore will not cause any adverse impact on the environment. The open water disposal of dredged material to the main channel will generate turbidity in the water column. However, at a typical open-water pipeline disposal operation, an estimated 97 to 99 percent of the fine grained dredged material slurry descends rapidly through the water column and impacts on the bottom (Barnard, 1978). Also, the turbidity is usually restricted to the vicinity of the operation and decreases rapidly with

TABLE 4.2 Submerged Diffuser Movement Schedule

Time Period	Recommended Height of Diffuser Above Bottom at Beginning of Time Period, m	Total Pumping Time (Days) Elapsed at Disposal Site for Dredge Sizes						Mound Height (H) at End of Time Period, m
		30 cm 12 in.	40 cm 16 in.	51 cm 20 in.	61 cm 24 in.	71 cm 28 in.	81 cm 32 in.	
1	1.0	0.4	0.2	0.1*	0.1*	<0.1*	<0.1*	0.6
2	1.5	3.8	2.1	1.3	0.9	0.6	0.5	1.2
3	2.1	13.0	7.3	4.5	3.1	2.3	1.7	1.8
4	2.7	30.8	17.3	10.6	7.4	5.5	4.2	2.4

Note: To be conservative all numbers beyond the first decimal place are ignored.

* For pipeline sizes exceeding 51 cm, the diffuser should be initially positioned 1.5 m above the bottom.

increasing distance from the operation. With the proposed submerged diffuser or a 90-degree submerged elbow in place, turbidity in the water column can be greatly reduced. The slurry remains in the pipeline/ diffuser until it is discharged at low velocity near the bottom, thus eliminating all interaction of the slurry with the water column above the diffuser. This effectively eliminates water-column turbidity as well as any depression of the dissolved oxygen levels in the water column (Schubel, et al., 1978; Neal, et al., 1977). Unfortunately, using the diffuser does not eliminate the impact of the sand burial on the benthic organisms. However, the main channel of the Upper Mississippi River is in general, sterilized and therefore the impact of the materials generated by disposal operation on the benthic organisms will be very minor. This point will be proven or disproven from the monitoring project.

A small portion of the disposed material may enter backwater areas downstream of the disposal sites. However, it should be pointed out that the dredging and disposal operations only disturb the local sediment transport during and immediately after the operation for a short while (say, from a few minutes to a few hours). After that, the river returns to its natural conditions. Therefore, only that portion of additional dredged material entering backwaters and side channels during and immediately after the dredging can be considered the result of dredging operations. After that, the sediment entering these areas should be considered part of the natural process, which should not be considered as impacts of dredging. Therefore, for monitoring of the biological impacts on the side channels and backwater areas caused by the dredging operations, only sampling before and immediately after the operation should be conducted.

4.3 DEVELOPMENT OF A DATA COLLECTION PROGRAM

This program specifies data needs, sampling frequency, sampling spacing and equipment and methods for collection and analysis of samples.

4.3.1 Data Needs

To obtain an evaluation of impacts of thalweg disposal, not only the physical properties but also the chemical and biological properties describing river environment should be determined. These data include:

1. Flow velocity field
2. Flow depth
3. Physical properties of bed material and dredged sediment (size, density and fall velocity).
4. Chemical properties of sediment (volatile solids, chemical oxygen demand, kjeldahl nitrogen, oil, grease, mercury, lead, zinc and other significant constituents).
5. Movement of dredged material disposed of in the thalweg.
6. Filling of dredged cuts.
7. Water quality at the disposal sites before, during and after the operation (water temperature, turbidity, pH, dissolved oxygen, organic matter, and suspended and dissolved constituents).
8. Changes in species composition, density and diversity of fish, mussel and benthos before and after the disposals.

Not all the data described above are required for every sampling session. The proposed data to be collected for various sampling periods are described in Section 4.3.3.

4.3.2 Equipment Needs and Methods for Collection and Analyses of Samples

The data described in the previous section can be collected using the following equipment and methods:

1. Flow velocity can be measured by current meters.

2. Flow depth can be measured by sonic sounding equipment.

3. Core samples of the bed material at selected sites can be collected for later analysis in the laboratory. The sampling sites should cover the area of dispersion of disposed material (see Section 4.3.3 for sampling spacing).

4. Water-sediment samples can be collected by pumping-type bottling samplers.

5. Fishery sampling by trawling.

The core samples of bed materials can be analyzed to determine their physical and chemical properties based on methods suggested by Guy (1969). These core samples can be analyzed using ultraviolet light to track the movement of disposed material by combining the counting rates of underwater TV monitoring records.

The turbidity of the water-sediment samples can be measured in terms of nephelometric method or visual method using a candle turbidimeter. The dissolved constituents can be determined according to the methods presented in the "Standard Methods for the Examination of Water and Wastewater" published by American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 13 edition, 1971. Also, the collected water-sediment samples, bed-material core samples and other biological samples will be analyzed to determine changes in species composition, density, diversity of the prime producers and the benthic fauna by adequate laboratory methods.

4.3.3 Sampling Frequencies and Spacing

The data collection periods can be divided into three phases.

1. Pre-Disposal Phase. The pre-disposal phase should determine baseline conditions before the disposal operation. Therefore, all the

data listed in Section 4.3.1 should be collected for this phase. Approximately ten water samples and 20 bed-material core (about 2 ft deep) samples plus some fishery samples and mussel surveys covering the dredging and disposal sites should be sufficient to provide adequate baseline conditions. Additional samples are required in side channels and backwater areas if they are within two miles downstream of the dredging site. The 20 bed-material core samples will also be analyzed to determine the hydraulic properties of tagged sediment and background fluorescence using the following procedure:

a) A core sample will be sliced into half and then examined by ultraviolet light to determine the background fluorescence and color.

b) Bed material in one-half sliced core sample will be tagged using a dye with distinguished color free from background interference following the procedure described in Section 4.2.2.

c) The fall velocities of the natural sediment from the untreated one-half core sample and of the tagged sediment will be measured in a fall velocity column.

d) The size distributions of the natural sediment and the tagged sediment will be determined by sieve analysis.

e) The natural sediment and the tagged sediment will then be mixed and examined using ultraviolet light to make sure that the tracer particles can be clearly distinguished. It is estimated that about one week will be required for collecting and shipping the bed material samples and about two weeks for preparing tracer particles and analyzing samples.

2. <u>During-Disposal Phase</u>. For the during-disposal phase, it is difficult to collect bed-material samples. Only water samples within the dredging and disposal affected areas will be collected for evaluation of water quality. About 50 samples, 10 samples during operation and four

sets of 10 samples each about 20 minutes apart after disposal operation, will be collected for water quality analysis.

3. Post-Disposal Phase. After the disposal operation when the initial disturbance has settled down (possibly overnight), the first data collection for the post-disposal phase will begin. All the data listed in Section 4.3.1 will be collected for this first session. Underwater TV monitoring system will first be towed on the river bed surface of the disposal site in longitudinal direction along the center of main channel to determine the length of disposal site. Then the TV camera will be towed transversely to cover the disposal area by about 10 evenly-spaced transects. At each transect, 5 bed-core samples will be collected. The number of tracer particles contained in each sample will be counted to determine the distribution of tracers as well as to derive a relation of tracer concentration over bed volume to that on bed surface. In addition, 2 bed-core samples and 2 water samples plus some fishery samplings and mussel surveys for each transect will be analyzed to investigate effects of dredging and disposal on chemical and biological properties at the disposal site. Additional samples are required in side channels and backwater areas if they are within two miles downstream of the dredging site.

As reported by many researchers through the Dredged Material Research Program supervised by the U.S. Army Engineer Waterways Experiment Station, dredging and disposal operations only cause localized and short-term impacts on water quality and chemical and biological properties. After that, the river returns to its natural conditions. Thereafter the variations in water quality and chemical and biological properties should be considered as natural processes, which should not be included as impacts

of dredgings. Therefore, to reduce the cost of conducting the demonstration program, it is adequate to only measure hydraulic variables, sound the bed profiles and monitor the movement of dredged material disposed of on thalweg by tracer tachnique for the subsequent data collection sessions for the post-disposal phase, without analyzing the samples for water quality and chemical and biological properties.

In general a typical hydrograph starts its high flow in late March, lasts through May and then flow recedes. Occasionally, floods may occur at the time when low flows generally occur. Dredging operations usually start at the beginning of low flow season. Assuming that a dredging and thalweg disposal operation is conducted in July, then the second data collection session for the post-disposal phase can be performed about one month after the disposal operation, say in August. This then is followed by the third session in November before the river freezes, the fourth session in late March or early April after the ice breaks, the fifth session in May of the following year during high flow and the sixth session in July to complete a year monitoring experiment. For each data collection session, TV monitoring camera will first be towed in a longitudinal direction to determine the extent of tracer dispersion. Then the TV camera will be towed transversely across the river to cover the entire dispersed area in 20 evenly spaced transects. Then three to five bed-core samples at each transect will be collected to determine tracer concentrations. This information will be correlated to the tracer number on the riverbed surface determined by the TV monitoring to track the movement of disposed material.

In summary, this data collection includes:

1. One complete data collection session for the pre-disposal

phase to analyze 10 water samples, 20 bed-material core samples and some fishery samplings and mussel surveys.

2. One water-quality data collection session for the during-disposal phase to analyze 50 water samples, 10 samples each in time sequence.

3. One complete data collection session for the post-disposal phase to analyze TV monitoring data, 50 bed core samples for the tracer analysis and 20 out of these 50 samples for chemical and biological properties, plus analysis of fishery and mussel survey samples.

4. Five tracer data collection section for the post-disposal phase to analyze TV monitoring data and about 60 bed core samples for tracer movement.

The collected data should be analyzed in a timely manner to evaluate the adequacy of the data collection program. The data collection program can be refined as the study progresses to reduce the cost and provide more meaningful information.

4.3.4 Cost Estimate

The cost required to collect and analyze data at each demonstration site can be estimated as the basis of:

1. Cost of tracers and required amount of tracer particles.
2. Cost of purchasing and setting up the equipment and supplies.
3. Manpower and cost required for collecting samples.
4. Cost of analyzing each sample in laboratory.
5. Manpower and cost for analysis of data.

As described in Section 3.4, the cost for conducting a flourescent tracer study would be roughly $52,000. This includes costs of about $6,000 for examining approximately 20 bed core samples to determine the

hydraulic properties of tracer particles and natural sediment and to assess background fluorescence at the site, which is broken down to about $1,500 for travel and sample collections, $1,000 for preparing tracer particles, $1,100 for determining fall velocity, $1,200 for determining size distributions, and $1,200 for determining background fluorescence and checking the visibility of tracer particles. This cost can be reduced if more than one site will be monitored. The costs of water quality, chemical and biological analyses are not included. For conducting the data collection program as described in the previous section, an additional $50,000 may be required. A minimum of monitoring three demonstration sites is required to evaluate the general applicabilities of thalweg disposal method. This would require approximately $300,000 for conducting the study, If a submerged diffuser is required to dispose of the dredged material, the cost for manufacturing this submerged diffuser is estimated to be $10,000. The device for feeding tracer particles through the pipeline to mix with dredged material costs about $2,000. It is apparent that the cost for conducting a tracer study is quite expensive. One alternative is to develop a combined one-dimensional and two-dimensional dispersion model to predict the dispersion of material. With the calibration of mathematical models using river contours, sediment and hydraulic data, the model can be applied to trace the movement of disposed particles and investigate related problems.

Chapter 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

The field experience, geomorphic study and mathematical model analysis all indicate that main channel (thalweg) disposal of dredged material can provide a feasible solution to the disposal problem in certain cases. A demonstration project can certainly improve our understanding of the applicability of thalweg disposal.

In this study, tracer methods are proposed for tracking the movement of dredged material disposed of in the main channel. Three categories of tracer methods were evaluated: fluorescent tracers, radioactive tracers and stable isotope tracers. After considering accuracy, safety, cost and other related factors, it is determined that the fluorescent tracer method is the most suitable method for this demonstration project. A demonstration project is then planned based on the decision.

The design of the demonstration project considers the selection of study sites, the design of the tracer method, and the development of a data collection program. The major results are summarized below:

1. Based on the knowledge of river characteristics, a suitable thalweg disposal site should be within the practical range of dredging so that the dredged material can be transported to the disposal site without excessive effort. There should not be severe dredging requirements, backwater areas and side channels immediately downstream of the disposal site.

2. Based on these criteria, a list of suitable and unsuitable thalweg disposal sites in Pools 11 through 22 in the Upper Mississippi River was compiled from a preliminary analysis of dredging records and

river geomorphology. However, because frequent or heavily dredged areas (reaches) are the ones with historic disposal site problems, the thalweg disposal concept should be proven or disproven in marginal and unfavorable sites regarding hydraulic suitability and identification of impacts on dredging requirements downstream. Potential sites at river mile 406, 355 and 332 (two unfavorable sites and one marginal site) were then identified.

3. The amount of fluorescent tracer particles required is about 15 tons if the quantity of dredged material is less than 350,000 cubic yards. Otherwise, the additional amount of tracer particles can be determined by using a tracer concentration of 33 ppm by volume.

4. Sand tracers can be produced by taking bed material from the study areas to be dredged and coating each grain with a thin layer of fluorescent plastic. Dye AX11 (pink), AX15 (orange), A19 (blue) manufactured by Day Glo Color Corporation, or other dyes which minimize background interference can be used to tag sand particles. It is expected that these tracer particles can retain their brilliance during the monitoring period (1 year). However, their hydraulic properties should be examined before utilization by comparing their fall velocities and sediment sizes with those of natural sediment.

5. An underwater TV monitoring system equipped with ultraviolet light can be used to photograph riverbed surface for later counting of tracer particles. Water turbidity in the Upper Mississippi River within the Rock Island District should have no significant effects on the efficiency and accuracy of the TV monitoring system at low and intermediate flows. However, effects of large turbidity at high flows require further evaluations. Some bed-material samples can be collected to determine the

relation between the number of tracers counted on the riverbed surface by the TV monitoring system and tracer concentration. With this TV monitoring system, an experienced operator can better define the sampling zone and make necessary adjustments to establish a more effective sampling program.

6. The transport pipeline in a hydraulic dredge should be modified for mixing tracer particles with dredged material in the pipeline before the dredged material is transported to the disposal site. A funnel tube with adequate valve controls can be connected to the transport pipeline upstream of the pump. Tracer particles can then be fed through the funnel tube into the pipeline at an adequate rate. The turbulence generated by the pump ensures uniform mixing of the tracer particles with the dredged material. Another method for mixing tracer particles with dredged material is by dumping tracer particles evenly on the site to be dredged. Then the dredging operation will automatically do the mixing. One potential of this latter method is the possibility of nonuniform mixing.

7. The pipeline discharge point should be modified to control the dispersion of dredged material slurry on the disposal site according to a predetermined pattern. A submerged diffusion system can be utilized to control the dispersion and to minimize the turbidity generated by open water disposal. Because the bed material in the Upper Mississippi River is relatively coarse, a 90-degree elbow submerged at a depth about 3 ft below the water surface to discharge dredged material can provide a reasonable slurry pattern.

8. The fluorescent tracer particles will not cause adverse impact on the environment. The turbidity generated by dredging and open water

disposal will be minor and localized. However, the open water disposal may cause impacts on the benthic organisms. Since the main channel of the Upper Mississippi River is in general sterile, therefore the impact on the benthic organisms should be minor. In any event, evaluation of the impact should be included in the demonstration project.

9. Data needs, equipment needs and methods for collection and analyses of samples are described in Sections 4.3.1 and 4.3.2.

10. Data collection periods can be divided into three phases: (1) pre-disposal phase, (2) during-disposal phase, and (3) post-disposal phase. One complete data collection session should be performed for the pre-disposal phase to determine the baseline conditions. One water-quality data collection session should be performed for the during-disposal phase. One complete data collection session should be conducted for the post-disposal phase. Then five subsequent tracer data collection sessions should be performed to trace the movement of disposed material and measure hydraulic variables.

11. The cost for conducting the data collection program at three demonstration sites was roughly estimated to be $300,000. This cost estimate is very preliminary and requires refining during the actual planning of the demonstration project.

5.2 RECOMMENDATIONS

A river reach can be generally categorized as a meander, a straight or a braided river with or without side channels and/or backwater areas. Ideally, typical reaches of each different river pattern should be investigated in the demonstration projects to evaluate applicability of main channel disposal techniques at different river conditions and

locations. However, the cost to implement this comprehensive demonstration project may be prohibitive.

Theories and knowledge of river mechanics, hydraulics, sediment transport, and biological responses can be used to analyze existing data or cursory field review to qualitatively evaluate the applicability of the main channel disposal of dredged material. To better evaluate the applicability of the main channel proposal and predict the river responses, the following alternatives are recommended for future studies:

(1) Use three-dimensional physical models of selected river reaches to investigate potential problems induced by thalweg disposal and to trace the movement of disposed material. The model study would enable us to visualize filling of dredged cuts and movement of disposed material. The study results would be very useful for improving knowledge of thalweg disposal and in designing the data collection program in the field demonstration project.

(2) Develop a combined one-dimensional and two-dimensional dispersion model to study the dispersion of disposed material. With the calibration of mathematical models using river contour, sediment and hydraulic data, the model can be applied to simulate the movement of disposed particles and investigate related problems. One advantage of the mathematical model is that the model can be easily modified to study different reaches of the Upper Mississippi River, and therefore is very effective in evaluating the general applicabilities of the thalweg disposal methodologies and developing criteria for its application. Also, the mathematical model can be utilized to study long-term impacts of main channel disposal of dredged material.

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